NACE
INTERNATIONAL

THE CORROSION SOCIETY

PCS 2

Advanced

July 2013

Version 1.0.0

IMPORTANT NOTICE:

Acknowledgements

The time and expertise of a number of NACE International members have gone into the revision of this course, PCS 2 Advanced. Their dedication and efforts are greatly appreciated by NACE, the author, and those who have assisted in making this course possible.

The scope, desired learning outcomes and performance criteria were developed by the Protective Coatings and Linings Task Group under the auspices of the NACE Education Administrative Committee in cooperation with the NACE Certification Administrative Committee.

NACE would like to particularly thank the task group for its work. Their efforts were extraordinary and their goal was in the best tradition of public service — to help improve corrosion control efforts industry-wide. This outstanding task group has *also* revised the NACE PCS 1 Basic Principles course *and* developed a valuable addition to the NACE Protective Coatings and Linings program, the new NACE PCS 3 Management course.

We also wish to thank their employers for being generously supportive of the substantial work and personal time that the members dedicated to this program.

This group of NACE members also worked closely with the contracted course developer from Elzly Technology Corporation, J. Peter Ault.

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Welcome to PCS 2 Advanced

PCS 2 Advanced provides advanced-level technology topics about protective coatings. Highlights include an in-depth discussion of coatings, their basic chemical properties, and any unique considerations for their surface preparation, application, and inspection.

The following topics are covered:

- Best practices
- Chemistry of liquid-applied coatings and coating formation theory
- Unique application and quality control methods
- Testing coating properties and defects
- Coating defects
- Substrate's unique surface preparation needs and applicable standards
- Coating system types; selection goals and objectives, performance requirements, design engineered properties, and trade offs
- Coating specifications: eliminating ambiguity, how to implement, identify shortcomings, and specification can negatively impact coating life
- Coating surveys and management programs

This course is suitable for planning, engineering, and supervisory level and technical personnel who work with protective coatings on a regular basis. Students should be able to learn basic chemistry concepts that pertain to coatings and corrosion.

General Course Information

PCS 2 Advanced spans three days with a final open-book two-hour exam on the third afternoon.

You MUST read the course material before the course begins to get the most benefit from the classroom presentations.

In addition to the content contained in the chapters and the slide presentations (replicated at the end of each chapter), you will find in the Appendices of the manual assorted NACE technical documents and other reference material.

Read all of the references so you will be familiar with important concepts and be better prepared for class discussions and activities. These materials have valuable information needed during the course and will be useful reference documents later in your career.

During the course, you should:

- participate in discussions and activities
- ask questions
- exchange ideas
- gather information

Class Activities

Several class activities will take place in small groups or teams. An individual from each team will present the results of the team's project. Each of you will have the opportunity to be your team's presenter during the course. The information comes alive and you will recall it more readily when you participate actively. We also use case studies to give you opportunity to apply some of the concepts and skills presented.

There will be two sets of review questions/quizzes to prepare you for the final exam. **Review and exam questions are drawn from both the material presented during the class presentations *and* the student manual**. The review questions are designed to help you check your understanding of the material, prepare for the final exam, and help the instructor check your progress.

The final, open-book exam determines whether you have the required grasp of the material. The exam is graded pass-fail, with a score of 70% or above required to pass.

Code of Conduct

While on site at a NACE course, appropriate behavior towards instructors, NACE/ class location staff, and fellow students is required. If appropriate behavior is not maintained, NACE has the authority to take proper action against the student(s) in violation, which could result in revocation of one or more of the following: NACE Certification, Membership, and current/future classroom attendance.

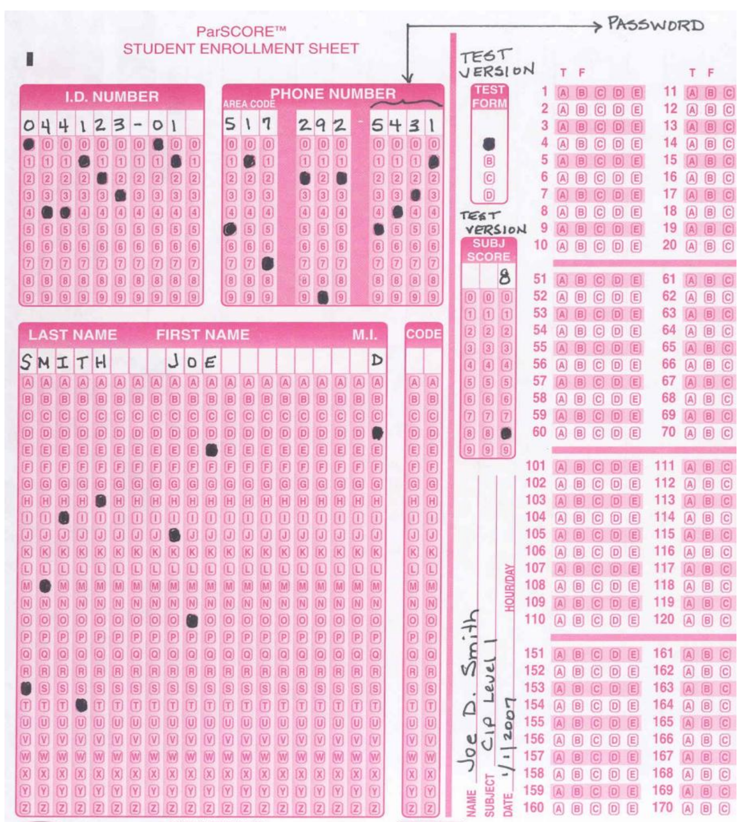
Instructions for Completing the ParSCORE™ Student Enrollment Score Sheet

1. Use a Number 2 (or dark lead) pencil.
2. Fill in **all** of the following information **and** the corresponding bubbles for each category:

√	ID Number:	Student ID, NACE ID or Temporary ID provided
√	PHONE:	Your phone number. **The last four digits of this number will be your password for accessing your grades on-line.** *(for Privacy issues, you may choose a different four-digit number in this space)*
√	LAST NAME:	Your last name (surname)
√	FIRST NAME:	Your first name (given name)
√	M.I.:	Middle initial (if applicable)
√	TEST FORM:	This is the version of the exam you are taking
√	SUBJ SCORE:	This is the version of the exam you are taking

√ NAME: _______________ (fill in your entire name)
√ SUBJECT: ____________ (fill in the type of exam you are taking, e.g., CIP Level 1)
√ DATE: _______________ (date you are taking exam)

3. The next section of the form (1 to 200) is for the answers to your exam questions.
   - **All answers MUST be bubbled in on the ParSCORE™ Score Sheet .** Answers recorded on the actual exam will NOT be counted.
   - If changing an answer on the ParSCORE™ sheet, be sure to **erase completely**.
   - Bubble only **one** answer per question and do not fill in more answers than the exam contains.



INSTRUCTIONS FOR ACCESSING SCORES ON-LINE

It is NACE policy not to disclose student grades via the telephone, e-mail or fax. Students will receive a grade letter in approximately 6-8 weeks after the completion of the course by US mail or through their company representative. However, in most cases, within 7-10 business days of receipt of exams at NACE headquarters, the students may access their grades via the NACE web site. The following are step-by step instructions for this process.

Spaces are provided below for you to fill in the information required to access grades. Please be sure to have this information filled in <u>before</u> leaving the course location. Keep this form with you upon leaving the course. You will <u>not</u> be able to access your grades without this information.

Go to the NACE Website at www.nace.org

Under the **Training & Certification** tab click on **Access Scores Online**

Then follow the **4 easy steps**:

Step 1: Find your **Course Number** in the drop-down list and click on it.

COURSE NUMBER: ______________________

The number listed above is your course number. You may also find it on your registration confirmation letter. If your course number does <u>not</u> appear in the drop down list then grades have not yet been posted.

Step 2: Enter your **Student ID** number

STUDENT ID: ______________________

This is your 6-digit NACE ID number or membership number (example 123456). This is printed on the roster provided to the instructor as well on your registration confirmation. For courses where no roster is provided, the instructor will assign a 10-digit temporary ID number used only for accessing scores on-line.

Step 3: Enter your **Password**:

PASSWORD: ______________________

This should be the last four digits of the telephone number you completed on your ParSCORE exam form. You may choose an alternate number but it must be in the last four spaces provided for the telephone number on the Scantron exam form

Step 4: Click on "**SEARCH**"

If you have trouble accessing your grade, please contact NACE International by e-mail at GradeQuestions@nace.org.

PCS 2 Advanced

List of References

American Concrete Institute (ACI) publication 515.1R, A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete

NACE SP0892, "Linings over Concrete for Immersion Service"

NACE TPC9 Publication, "User's Guide to Hot Dip Galvanizing for Corrosion Protection in Atmospheric Service"

NACE No. 12/AWS C2.23M/SSPC-CS 23, "Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and their Alloys and Composites for the Corrosion Protection of Steel"

SSPC-TR 4/NACE 80200, "Preparation of Protective Coating Specifications for Atmospheric Service"

Corrosion Prevention by Protective Coatings, Charles G. Munger

NACE SP0178, "Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to be Lined for Immersion Service"

NACE SP0188, "Discontinuity (Holiday) Testing of Protective Coatings"

Chapter 5: Specialty Coatings

OBJECTIVES

After completing this chapter you will be able to:

OBJ 5.1: Understand the various types of specialty coatings and their associated application processes.

OBJ 5.2: Understand the characteristics and advantages or disadvantages of each of the specialty coatings.

OBJ 5.3: Understand the uses/applications, health and safety concerns, and governing standards of the each of the specialty coatings.

There are a number of different types of specialty coatings available in the market today. Some of the various types of specialty coatings include:

- Hot-dip galvanizing
- Fireproofing
- Thermal spraying
- Rubber linings
- Glass linings
- Fiber reinforced plastic (FRP)

The chapter will describe the various types of specialty coatings and their associated application process, characteristics, advantages or disadvantages, health and safety concerns (if applicable), uses/applications, and governing standards.

5.1 Hot-Dip Galvanizing

Hot-dip galvanizing immerses an object in a bath of molten zinc metal for a short period of time. It is the primary method used to apply zinc to steel and has to be one of the most cost effective, corrosion resistant coatings.

In hot-dip galvanizing steel, all mill scale and other impurities must be removed from the steel surface before it is dipped into molten zinc. The zinc coating protects the base metal from corrosion by providing both a barrier from the environment and sacrificial cathodic protection. If the surface becomes scratched, exposing the base metal, the zinc coating is slowly consumed while the substrate remains protected.

5.1.1 Types of Hot-Dip Galvanizing

Two hot-dip galvanizing processes are used to coat a variety of metal substrates:

- Continuous line galvanizing
- After fabrication galvanizing

5.1.1.1 Continuous Line Galvanizing

A small amount of aluminum added to the zinc bath minimizes formation of the iron-zinc alloy. Adding aluminum gives the steel a uniform coating with good adhesion and enough flexibility to allow folding and movement of the sheet steel without much damage to the coating. Nearly all hot-dip galvanized sheet steel and strip steel used in industry is produced by the continuous line process.

The weight of the zinc coating applied in the continuous line process varies from 0.5 oz/ft2 –2.75 oz/ft2. Typical zinc sheets have 0.5 to 2.0 mils of zinc per side.

The zinc coating applied by continuous line galvanizing is very different from an after fabrication because there is little alloying of the steel with the zinc. The result is a clear definition between the zinc coating and the steel as shown in Figure 1.1.

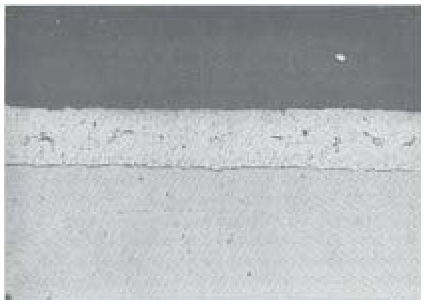


Figure 5.1 Metallurgical Cross Section of Continuous Line Galvanized Steel

5.1.1.2 After Fabrication Galvanizing

This process can be used to apply zinc to steel parts ranging from small pieces (nuts and bolts) to large structures (tanks, guard rails, transmission towers, bridge beams). A great deal of structural steel gets corrosion protection from hot-dip galvanizing each year. It can coat all surfaces of complex parts, if designed properly. Although it is a fairly simple process, it is very effective and has been used continuously since the 1800s.

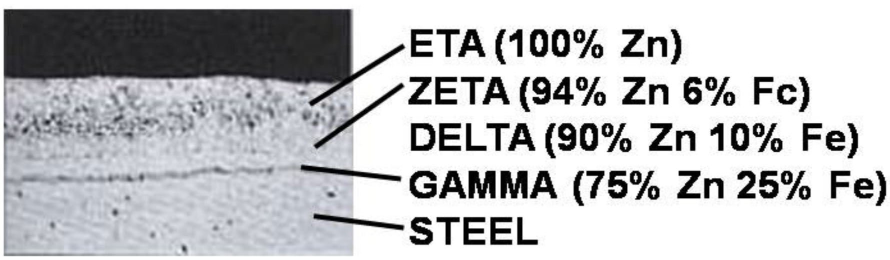


Figure 5.2 Alloy Layers in Hot -Dip Galvanizing

During after fabrication galvanizing, the zinc forms an alloy with the steel, providing maximum adhesion between the metals. There is no clear distinction between the zinc and steel, but there is a gradual progression of zinc and iron alloy from pure zinc to pure iron, as shown in Figure 5.2. As a result, a strong bond develops between the zinc and the steel.

The integrity of the zinc coating and its thickness are influenced by a number of factors, including the composition of the steel, geometry of the steel part, condition of the steel substrate, the length of time in the bath, the rate of withdrawal from the bath, and the cooling rate.

If the steel is thoroughly cleaned, a continuous coating forms over the surface, encompassing rivets, welds, and edges of complicated fabricated structures. Sharp corners, recesses, and inaccessible areas are all effectively coated by after fabrication galvanizing. Because all surfaces are coated during immersion, galvanizing also provides both inside and outside protection for hollow structures. Small or threaded parts may be centrifuged after hot-dipping to remove any excess zinc.

5.1.2 Application Process for Hot-Dip Galvanizing

There are several stages in the hot-dip galvanizing application process, including:

- Surface preparation
- Zinc bath
- Post treatment
- Inspection

5.1.2.1 Surface Preparation

The cleanliness of the steel surface is critical to successfully applying a galvanized coating since the molten zinc fuses with the base metal to form a metallurgical bond. The material to be hot-dip galvanized should be free of welding slag, mill scale, paints, varnishes, oil, and grease. Overlapping surfaces should be cleaned before dipping because any residual oil and grease may trap moisture, which creates a safety hazard during hot-dipping. Immersion in the molten zinc changes trapped moisture into steam, causing miniature explosions in the zinc bath; this produces uncoated areas and creates a potential hazard.

In most hot-dip galvanizing facilities, cleaning is a four step process. First, the piece is degreased by immersion in a hot caustic bath (65–82°C [150–180°F]) or a similar solution to remove oil, grease, and other organic contaminants. This alkaline cleaning process is intended to wash contaminants from the surface and enhance the removal of oil films.

Second, it is rinsed with clean water. Third, the work piece is immersed in a mineral acid (usually sulfuric acid or hydrochloric acid) bath to remove rust, mill scale, and other inorganic contaminants. Sulfuric acid baths are always heated (60–79°C [140–175°F]). Hydrochloric acid solutions are normally used at ambient temperatures (24°–38°C [75–100°F] to prevent excessive fuming. Fourth, the work piece is rinsed with clean water.

5.1.2.2 Zinc Bath

All types of carbon and alloy steels as well as iron and steel castings can be galvanized. Strip or wire coating may be continuously coated by dipping, often at high speeds. Sheet steel is continuously galvanized in the same fashion as strip or wire. Fabricated articles can be mounted on jigs and dipped in batches or individually as shown in *Figure 5.3*. Small items, such as nuts and bolts, are dipped in perforated baskets as shown.

Figure 5.3 Fabricated Steel Entering a Zinc Bath

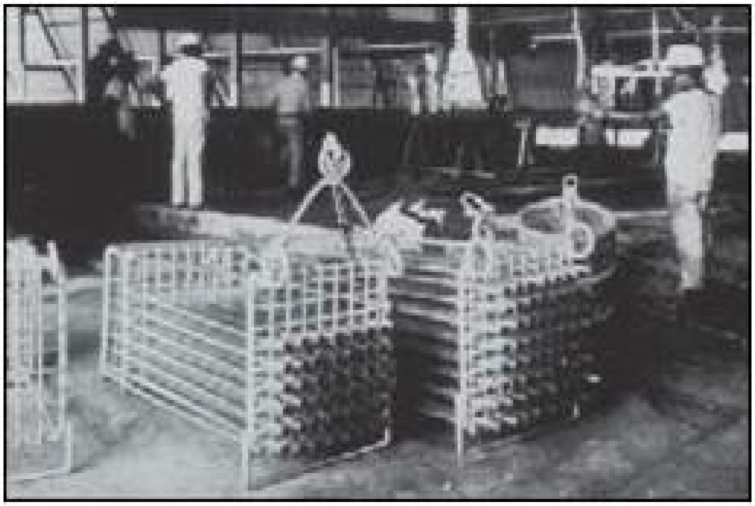


Figure 5.4 Small Parts to be Galvanized in Baskets

Generally, the most economical and highest quality galvanizing is done when the entire work piece can be totally immersed in the molten zinc in one dip. Objects larger than the kettle can be galvanized by a procedure referred to as *double dipping* — first dipping one end and then the other. With this method, 50 percent or more of the object's surface is immersed in the molten zinc. When the galvanizing of that portion is completed, the article is turned over, and the remaining uncoated portion is lowered into the zinc bath.

The work piece remains submerged in the molten zinc bath until the alloying reaction is complete. Depending on the thickness of the steel, this process can take as little as 30 seconds. Once the work piece attains the temperature of the zinc bath, which may vary from 830–870°F (445–465°C), the alloying process has taken place.

When the work piece is placed in the kettle the zinc bath bubbles and sputters and may splash from the kettle. The bubbling stops when the work piece reaches the bath temperature; the steel is then withdrawn from the kettle. The rate of removal determines the thickness of the unalloyed zinc layer remaining on the work piece.

If the work piece is withdrawn at the same rate at which the zinc drains freely from the surface, the top zinc layer will be evenly distributed. When the work piece is withdrawn too quickly from the bath, the surplus zinc runs down the surface until it solidifies, resulting in a lumpy, uneven coating.

Once the work piece is withdrawn from the kettle, it is air cooled or immersed in a water quench tank. The quench operation freezes any further alloying between the steel and the zinc coating. If proper cooling does not occur, the pure zinc layer will continue to be converted to iron-zinc alloy, changing the surface properties and discoloring the surface. This can affect the corrosion resistance of the coating.

5.1.2.3 Post Treatments

Post-treatment processes vary. They are performed to produce one or more of the following results:

Reduce coating thickness: The molten metal that adheres to the article is removed as it leaves the bath. This is done by rolling (continuous line only), wiping, centrifuging, or air blasting. The galvanizing method determines the technique for coating thickness reduction. Both continuous-line and after-fabrication galvanizing must be done while the coating is molten.

Improve properties or appearance: Coating properties and/or appearance can be improved by chromating, phosphating, light rolling, and roller leveling. Light rolling and roller leveling are used with continuous-line galvanizing only. Painting after galvanizing also enhances corrosion protection and appearance. If a galvanized piece is to be painted, it should not be chromate quenched because the chromate quenching process may interfere with paint adhesion.

All post treatment processes immediately follow hot-dipping are regarded as part of the coating process.

5.1.2.4 Inspection

At each step during and after the hot-dip process, the work piece should be inspected to ensure compliance with the specification. Visual inspection and a variety of simple laboratory and field tests can be done to determine thickness, coating uniformity, coating adhesion, and appearance. In addition, embrittlement and defects resulting from fabrication and design are considered during inspection.

Inspection of the galvanized product is normally conducted at the galvanizer's plant prior to shipment. Because the service life of a galvanized coating is directly related to the zinc coating thickness, thickness becomes the most important check of galvanized coating quality.

5.1.3 Characteristics of Hot-Dip Galvanizing

5.1.3.1 Thickness

The service life of the hot-dip galvanized coating is directly related to the thickness of the protective zinc. The galvanized coating thickness is influenced by the following factors:

- Steel thickness and geometry
- Galvanizing bath temperature
- Steel chemistry
- Immersion time in the bath
- Surface condition of the substrate
- Rate of withdrawal from the bath

Generally, thicker steel will produce thicker coatings. Larger items will also produce thicker coatings because they are normally immersed for longer periods. Hot rolled sections produce thicker coatings than cold formed sections because they exhibit a rougher as-rolled surface.

5.1.3.2 Thickness Measurement Methods

Average thickness is determined by weight. The item to be galvanized is weighed before and after galvanizing. The weight of the zinc coating is determined by dividing the weight gain by the total surface area of the galvanized piece.

For example, a total weight gain of 24 oz (680 g) over a total area of 10 ft^2 (approximately 1 m^2) would equal 2.4 oz of coating per square foot (680 g/m^2). Table 1 from the ASTM Book of Standards Vol. 01.06, provides specifications for coating weight requirements for some hot-dip galvanized products.

5.1.3.3 Conversion between Weight and Thickness

Weight may be converted to an estimated average measurement by multiplying the weight of the coating by a conversion factor. The conversion factor is 1.7 to obtain an estimated average thickness measurement in mils when the weight is given in ounces per square foot. To obtain an estimated average thickness in micrometers when the weight is given in grams per square meter, the conversion factor is 0.14. For example, if the coating weight is 1 oz/ft^2 (305 g/m^2), the estimated average thickness will be 1.7 mils (43 µm).

5.1.3.4 Appearance

The basic finish requirements of a galvanized coating are that it be relatively smooth, continuous, lustrous, and free from gross surface imperfections (e.g., cracking, peeling, bare spots, lumps, blisters, and inclusions of flux, ash, or dross). Smoothness is a relative term, and the job specification must set tolerances for smoothness.

Visual inspection of hot-dip galvanized articles may detect:

- Bare spots
- Dull-gray galvanized coating
- Rust stains
- White rust

Photos of several of these conditions can be found in NACE Publication TPC 9, "User's Guide to Hot-Dip Galvanizing for Corrosion Protection in Atmospheric Service."

Whether or not the conditions found on hot-dip galvanized steel are grounds for rejection depends on the job specification. Some of these conditions do not always compromise the corrosion resistance of the coating, and it is important that the buyer and the fabricator have a mutual understanding of what constitutes unacceptable work.

5.1.3.5 Corrosion Resistance

As mentioned previously, hot-dip galvanizing provides both barrier and sacrificial protection. The zinc coating acts as a barrier by isolating the steel from the electrolytes in the environment. The degree of barrier protection is influenced by adhesion to the steel and abrasion resistance. The toughness of the galvanized coating enhances its ability to maintain its integrity during shipment and/or rough handling on the job site.

If the coating is damaged, galvanizing offers sacrificial cathodic protection to the exposed steel. Hot-dip galvanizing ensures that the base metal becomes the cathodic element in the corrosion circuit. The zinc sacrifices itself, normally over a long period of time, to protect the steel.

Aqueous Corrosion

Hot-dip galvanizing offers good corrosion protection in aqueous environments at room temperature and a pH range of 5.5 to 12.5. It is used on steel in fresh water and offers considerable protection when immersed in seawater or exposed to salt spray. In the immersion environment, potential galvanic corrosion issues need to be recognized. Galvanizing on a small part can be quickly consumed if it is coupled to a large cathode. For example, a galvanized bolt used to fasten uncoated stainless steel in immersion can lead to quick consumption of the galvanizing on the fastener.

Fresh water includes all types of water except seawater and includes domestic, industrial, river, and lake waters. The degree of corrosion of zinc in fresh water is influenced by the impurities in the water, including microorganisms, soil, decaying organic matter, and dissolved salts of calcium, magnesium, iron, and manganese. In addition, pH, temperature, and motion determine the structure and composition of corrosion products that form on the surface.

Variances in the amount and type of impurities can alter the type of corrosion product and formation rate. Water with a relatively high level of free oxygen or carbon dioxide is more corrosive to hot-dip galvanizing than water with less oxygen and carbon dioxide. Hard water is less corrosive to galvanized coatings than soft water. The increased concentrations of insoluble salts in hard water combine with the zinc on the galvanized surface to form a protective barrier of calcium carbonate and zinc carbonate.

Although the factors that influence corrosion of zinc in fresh waters apply to seawater, the dissolved salts (mainly sulfides and chlorides) in seawater are the primary influences on corrosion of zinc in seawater exposures. With high levels of chloride in seawater, one would expect a high

rate of zinc corrosion. However, magnesium and chloride ions found in seawater strongly inhibit zinc corrosion in this environment.

5.1.3.6 Soil Corrosion

Soil texture and drainage affect the rate of zinc corrosion. Coarse soils such as gravel and sand allow air to circulate freely. In these soils, the zinc corrosion process is similar to that in atmospheric corrosion. Fine textured soils such as silt and clay hold water, resulting in poor air circulation and drainage. Zinc corrosion in these types of soil resembles the corrosion process in water. Galvanized coatings have been shown to prevent pitting of steel in soil, just as they do in atmospheric exposures. Even when the zinc coating is consumed, the underlying steel has been less corroded than bare steel in identical soil conditions.

5.1.3.7 Chemical Resistance

The pH of the chemical solution is a prime factor in determining corrosion behavior of a galvanized coating. Hot-dip galvanizing offers good chemical resistance and therefore corrosion protection in solutions with pH ranging from above 5.5 to below 12.5. In this range, a protective film forms on the galvanized surface and slows corrosion. Agitation, aeration, temperature, and the presence of inhibitors also influence the corrosion rate in liquid chemical environments.

Galvanized steel containers are widely used to store and transport many chemical solutions. The following commonly used chemicals have been successfully stored in hot-dip galvanized containers:

- Hydrocarbons
- Alcohols
- Halides
- Nitriles (cyanides)
- Esters
- Phenols
- Amines and amine salts
- Amides

5.1.4 Advantages of Hot-Dip Galvanizing

Hot-dip galvanizing offers the following advantages as a specialty coating:

Cost effective: Galvanizing can be more cost-effective than other coatings because it lasts longer.

Long service life: In most rural environments, hot-dip galvanized coatings have been found to protect surfaces for over 50 years. Galvanized coatings can protect for 20-25 years in both severe coastal and urban exposures.

Resistance to mechanical damage: Galvanizing’s unique metallurgical structure provides excellent resistance to mechanical damage from transportation and field erection activities as well as service stress.

Fast erection time: Galvanized pieces are ready for installation upon receipt. It requires cooling but not curing. No time is lost due to on-site surface preparation, additional galvanizing, or inspection.

5.1.5 Health and Safety Concerns during Hot-Dip Galvanizing

The following items are unique health and safety concerns that need to be observed and noted for hot-dip galvanizing:

- Hot-dipped articles stay hot. Allow the article to cool before touching it.

- Molten metal can splash out of the kettle and travel some distance.
- Nascent hydrogen may burn off in the air above the kettle.
- Traditional safety concerns with industrial processes need to be observed.

5.1.6 Uses / Applications of Hot-Dip Galvanizing

Hot-dip galvanizing can be used to coat a variety of fabricated and non-fabricated products. Items include:

- Wire
- Tanks
- Pipes
- Tubes
- Fittings
- Hardware
- Wire cloth
- Hollow-ware.

5.1.7 Standards for Hot-Dip Galvanizing

The following standards apply to hot-dip galvanizing. You may find additional information concerning the processes in these standards.

- **ASTM A 123** "Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products"
- **ASTM A 143** "Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement"
- **ASTM A 153** "Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware"
- **ASTM A 384** "Standard Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies"
- **ASTM A 385** "Standard Practice for Providing High-Quality Zinc Coatings (Hot-Dip)"
- **ASTM A 780** "Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings"
- **ASTM B 6** "Standard Specification for Zinc"
- **ASTM B 602** "Standard Test Method for Attribute Sampling of Metallic and Inorganic Coatings"
- **ASTM E 376** "Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current Electromagnetic Test Methods"

Please refer to the NACE TPC9 Publication, "User's Guide to Hot-Dip Galvanizing for Corrosion Protection in Atmospheric Service," for additional ASTM standards related to hot-dip galvanizing.

5.2 Fireproofing Coatings

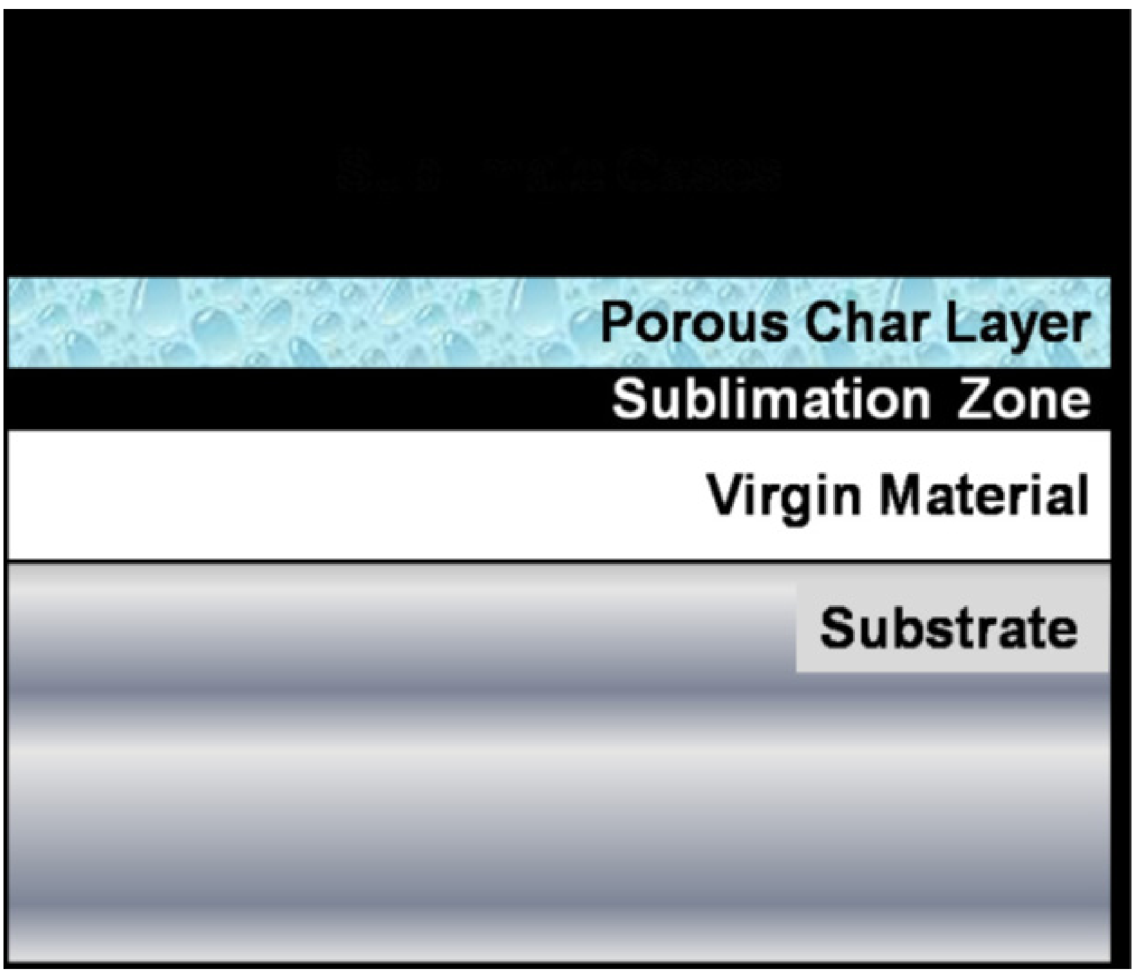
Fireproofing coatings in general provide passive fire protection. They enable structures to remain standing and allow egress time for people. The typical use of fireproofing coatings includes structure steel, divisions, or equipment that is very valuable and areas where there is threat of serious damage or structural failure.

5.2.1 Types of Fireproofing Coatings

Fire protective coatings are categorized as spray applied fire resistive material (SFRM), subliming and intumescent. They absorb heat through mass reduction. Both of these coating types must be replaced after a fire. SFRM coatings absorb heat and release steam; subliming coatings absorb heat and loose mass, while intumescent coatings react to heat and quickly swell to insulate the structure from fire's heat.

5.2.1.1 Subliming Coatings

Sublimation uses massive amounts of thermal energy to transform a solid material directly into a vapor without an intermediate liquid stage. Subliming coatings are based on this process. Subliming coatings maintain the temperature of the substrate at the temperature of sublimation during the chemical reaction creating a counter-flow of gases to block the fire's heat. A porous char layer forms on the surface of the subliming coating providing cellular insulation and a radiating heat shield to delay heat penetration to the substrate (See Section 5.2.2 Application



Process for Fireproofing). The fire rating of subliming coatings is mostly determined by the coating thickness.

5.2.1.2 Intumescent Coatings

The "Paint/Coatings Dictionary" of the Federation of Societies for Coatings Technology defines intumescent coating as:

". . . a fire-retardant coating, which, when heated, becomes plastic and produces nonflammable gases, such as carbon dioxide and ammonia. The gases are trapped by the film, converting it to foam about fifty times as thick as the original paint film. At this stage, the film solidifies, resulting in a thick, highly-insulating layer of carbon, which effectively protects the substrate from fire."

The char protects and insulates the substrate, reducing heat gain, which delays or prevents structural collapse.

Figure 5.5 Left: Test columns prior to burn. Right: Intumescent coating after burn. (Photos courtesy of Carboline Company)

5.2.1.3 Types of Fires

There are three general types of fires:

- Hydrocarbon fires - burn faster and quicker
- Celluosic fires - typical building fire
- Jet fire – chemically based fire under pressure

5.2.2 Application Process for Fireproofing

5.2.2.1 Subliming Coatings Application Process

Surfaces must be prepared according to manufacturer recommendations or specification requirements. This usually requires the steel substrate to be cleaned and degreased prior to grit blasting in accordance with NACE No. 2/SSPC-SP 10, "Near-White Metal Blast Cleaning." A minimum anchor pattern of 0.002 in. (0.05 mm) is typically recommended. Degreasing may be done by hot water washing, the use of cleaning agents, steam cleaning, or solvent washing. The substrate must be clean, free of rust, and dry before the prime coat is applied.

Subliming coatings can be spray or trowel applied. Depending on the material, conventional or airless spray can be used. Specialized plural-component airless spray equipment is used for 100 percent solids materials which have short pot lives.

If the specified thickness cannot be obtained in a single coat, the applied material should be allowed to cure sufficiently to support the weight of any subsequent coats. Fiberglass or wire mesh reinforcement may be required for high film thicknesses of some materials. After half the specified coating thickness has been applied, fiberglass or wire mesh reinforcement is put in place.

Subliming coatings require a top coat. The top coat must be compatible with the fire protective coating and be recommended by the coating manufacturer for service in the specified environment. If a top coat is not applied within the maximum allowable time, manufacturers requirements for preparing the coating should be followed (commonly solvent activation).

5.2.2.2 Intumescent Coatings Application Process

Surfaces should be prepared in accordance with manufacturer recommendations or specification requirements. Often this requires steel surfaces to be clean and prepared with a 38 µm (1.5 mil) to 50 µm (2.0 mil) anchor pattern. The primer is applied when the steel surface is clean, dry, and free of contaminants. The choice of primers and the primer thickness can significantly influence the performance of the intumescent coating. The following primer systems can be used:

- Polyamide epoxy
- Alkyds
- Zinc-rich epoxy, with an epoxy tie coat
- Ethyl silicate inorganic zinc primers, with an epoxy tie coat

Intumescent coatings are applied to a specified thickness that is determined from fire rating tests and reflects the intended performance requirements. Intumescent coatings may have a matte or orange peel appearance. If a smoother finish is desired, some coatings such as epoxy intumescents may be thinned with a solvent approved by the manufacturer and roll-applied.

Top-coating may be desired for aesthetics or required per third party certification; it is recommended for intumescent coatings in moist environments and where acid resistance is important. Polyurethane, epoxy, and acrylic coatings may be used as top coats the manufacturer should be consulted for their recommendations.

Some intumescent materials are designed to be used with reinforcement. Fiberglass or carbon-fiber mesh is used for structural steel columns, beams, tees, angles, channels, and hollow sections. The reinforcing mesh is applied per the individual certification, but it is typically placed at mid depth of the coating thickness.-

5.2.3 Characteristics of Fireproofing

5.2.3.1 Subliming Coating Characteristics

Subliming coatings are epoxy-based and have been used to protect structural steel, bulkheads, oil and gas piping, gas and oil storage tanks, electrical cables, conduits, and cable trays. In addition to fire protection, they also offer corrosion protection and excellent chemical resistance.

5.2.3.2 Intumescent Coatings Characteristics

Intumescent coatings are available in water based, solvent based (thin film), and epoxy based (mastic) forms. Each one has its own purpose. Water and solvent based are most common on interior structures due to their quality of finish. Epoxies are the work horse for exterior protection due to their higher resistance to weathering. An epoxy primer is recommended for use with intumescent coatings. However, only the vinyl-based mastic requires an epoxy top coat. Intumescent coatings offer fire and corrosion protection as well as resistance to disbonding, cracking, and peeling.

Thin (0.4 mm to 3.3. mm [16 mils to 130 mils]) intumescent coatings may be used in laboratories, hospitals, processing plants, and other facilities where aesthetics are important. These coatings are covered with a decorative top coat that also provides a protective finish. In addition to offering fire and corrosion protection, these coatings are impact and abrasion resistant.

5.2.3.3 Level of Protection

The level of protection for a specialty coating has an assigned comparative fire rating in accordance with third party testing. These may include the Underwriters Laboratory (UL) 1709, UL 263, ASTM E119, etc. The level of fire protection required is determined by the intensity and duration of a potential fire and the importance of the structure or equipment to be protected.

An example is three-hour fireproofing, as defined by Underwriters' Laboratories (UL) as protecting columns from 1000°F temperatures for three hours. Three-hour fireproofing is generally applied to main structural support members of valuable structures and equipment. General criteria for three-hour fireproofing include:

These characteristics can include the protection of people or structures. The fire ratings need to match local fire codes/regulations as well as owner requirements. Specific tests determine the comparative fire rating of this specialty coating. They are tested as complete assemblies or coating systems at prescribed thicknesses. For example, the primer is part of the rated and tested fireproofing system, and any untested primers may need to be removed. The dry film thickness (DFT) is critical to the fire rating, and it must comply with the specifications. The installed circumstances of the fireproofing system (restrained versus unrestrained) impacts the thickness required to meet the fire rating.

5.2.4 Uses / Applications for Fireproofing

The primary uses of fireproofing coatings include the structural steel in buildings and in refineries and chemical plants. Specifically in refineries and chemical plants, these coatings are used for the following items:

- Structural steel
- Vertical vessel skirts
- Hydro processing reactor skirts
- Legs for horizontal vessels
- Overhead pipe stanchions
- Elevated support structures
- Offshore structures
- Hollow supports

As a general rule, all structural load bearing members located within 50 ft. of fire hazard equipment, such as heaters and furnaces, pumps or compressors, drums, or tanks with flammable materials, should be fireproofed.

5.3 Thermal Spray

Thermal spray is a generic term applied to several processes that deposit finely divided metallic or nonmetallic materials in a molten or semi-molten state onto a properly prepared substrate. This curriculum will primarily address thermal spray processes used to apply metallic coatings. Also called *metallizing,* these processes include flame spray, plasma spray, and arc spray.

5.3.1 Types of Thermal Spray

The following types of thermal spraying are used to deposit molten or semi-molten metal onto a prepared substrate:

- Electric-arc
- Flame spray (combustion)
- Gas-plasma thermal spray
- Non-transferred arc plasma spray
- Plasma-transfer arc spray
- High velocity oxygen/fuel (HVOF)

5.3.1.1 Electric-Arc

The electric-arc process, traditionally used to apply metalizing to ferrous-based and nonferrous alloys, provides low operating costs for electricity and air, dense coatings, ease of use, and variability in wire use. Two wires, which may be solid or metal cored, are electrically shorted. The high current flow across the wires causes the ends to melt. Compressed air then transfers molten droplets to the surface. Wire is continuously fed such that the process repeats itself. The electric-arc process differs from the other thermal-spray processes in that there is no external heat source. Heating or melting takes place when the two electrically opposed charged wires are fed together in such a manner that a controlled arc occurs at the intersection.

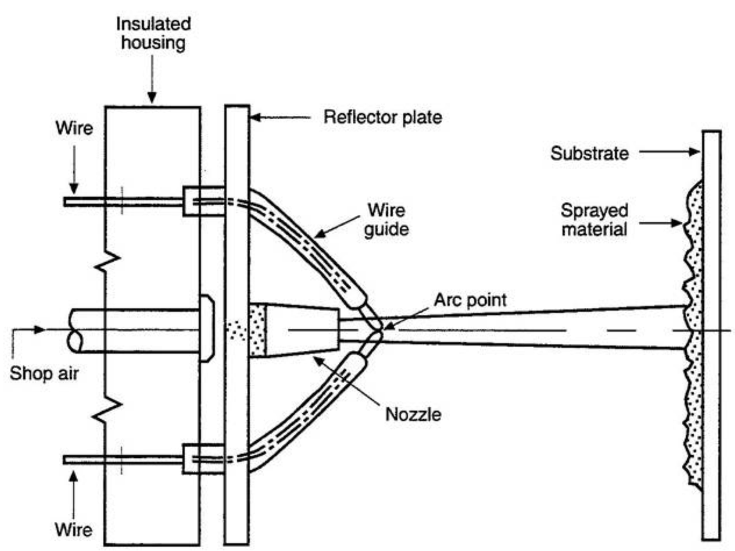


Figure 5.6 Typical Electric-Arc Spray Device

The electric-arc spray process offers the following advantages over the combustion (gas-flame) process:

- Higher bond strengths (greater than 3,000 psi [21 MPa])
- High deposition (rates up to 120 lb/h [55 kg/h])
- Lower substrate heating temperatures since the flame does not touch the surface
- More cost-effective operation than other processes

5.3.1.2 Other Types

Other types of thermal spraying include:

- Flame spray
- Gas-plasma
- Non transferred-arc plasma spray
- Plasma-transfer-arc (PTA) spray
- High velocity oxygen/fuel (HVOF)

5.3.1.3 Flame Spray (combustion)

The flame spray (combustion) process was developed in the early 1900s. It is the oldest thermal spray technique. In the combustion process, powdered alloys or wires are fed into a flame and transferred with or without compressed air to the substrate. The flame is usually created by mixing oxygen with a fuel gas, such as acetylene, and then ignited. Other common gases used in the combustion process include propane, Mapp gas, and oxygen-hydrogen. Most flame spray guns can be adapted to use several combinations of gases. Normally, altering the nozzle and/or air cap adapts the gun to a particular gas. The feedstock, either wire or powder, is fed into the center of the flame, heated, and propelled against a substrate. Flame spray guns are available to spray materials in rod, wire, or powder form.

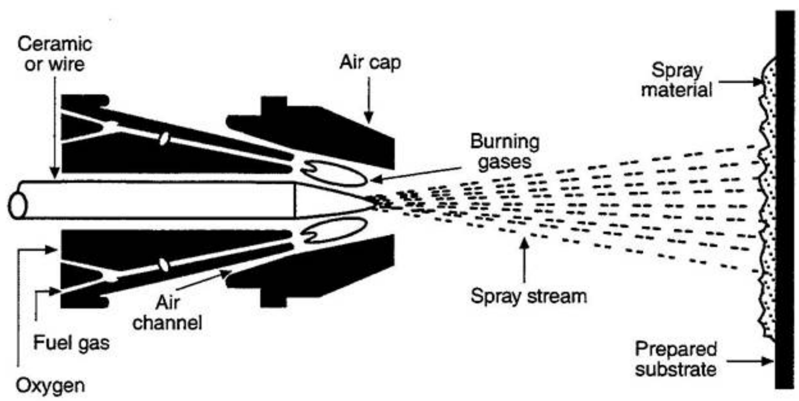


Figure 5.7 Cross-Section of Typical Wire or Rod Flame Spray Gun

Combustion powder is used extensively for the production of fusible coatings and for general use restoration coatings. The powders include ferrous, nonferrous, and ceramic materials. The powder is fed into the combustion equipment by gravity or by a powder feeder, which uses positive pressure to force the powder into a line attached to the spray gun.

Combustion wire has been used for stainless steel and nonferrous alloys. A solid wire is fed into the combustion flame, and compressed air is used to transfer the molten alloy to the surface. This process was used extensively for corrosion control until the cost and performance benefits of electric-arc and high velocity oxygen/fuel (HVOF) techniques became known. The use of HVOF continues to increase.

In general, the combustion process is characterized by low capital investment, high deposition rates, and relatively cost effective maintenance. The combustion thermal spray process generally results in coatings with low bond strengths and high porosity. In addition, the technique provides a more narrow range of working temperature and high heat transmission to the surface than plasma-arc and electric-arc spray methods.

5.3.1.4 High Velocity Oxygen/Fuel (HVOF)

Some thermal ray processes include high velocity oxygen/fuel (HVOF) systems, which produce very dense coatings. Powdered alloy feedstock is fed into a chamber and accelerated toward the substrate at very high velocities. The process involves injecting a fuel gas with oxygen into a combustion chamber. The combustion gases are discharged through ports in the combustion head increasing the gas velocity to hypersonic speeds. Powder is injected into the intersection of the discharge ports by using a carrier gas such as argon. Flame temperatures are relatively low (2,900°C [5,250°F]). The high velocity and low application temperature require a finer particle powder and tighter particle size control than other thermal spray techniques.

While conceptually similar to combustion spray technology, it must be emphasized that the resultant coating is substantially different. The ability to apply the molten product at hypersonic speeds produces very dense coating on the substrate without any of the porosity common to conventional thermal spray. In many applications HVOF can be substituted for plating applications, such as chrome used for hard wear surfaces.

5.3.2 Application Process for Thermal Spraying

The application process for thermal spraying includes:

- Surface Preparation
- Surface pre-heat (optional)
- Metallized coating application
- Finishing (optional)
- Inspection

5.3.2.1 Surface Preparation

Thermal spraying is intolerant of inadequate surface preparation. It requires perfectly clean metal, which is usually specified for white metal preparedness. Pre-cleaning must remove all oil, grease, dirt, chemical salts, etc, as required by the contract and specifications. Abrasive blasting is the methodology typically specified for thermal spraying, and the standards for cleanliness are covered by NACE No.1/SSPC SP-5. The anchor pattern may vary from 50 to 150 microns (2 to 6 mils), and there must be an angular profile.

5.3.2.2 Surface Preheat

Preheating temperatures must be monitored by an inspector using either a contact or infrared non-contact thermometer. Preheating can improve adhesion of the thermal spray coatings, and it ensures the surface is dry prior to coating application.

5.3.2.3 Metallized coating application

Successful metalized coating application is dependent on the following factors:

- Type of application equipment
- Spray angle (perpendicular)
- Distance from surface
- Speed of the gun movement must be a controlled and steady pass
- Consistency of application
- Multiple passes
- Applicator training

5.3.2.4 Finishing

Corrosion products of zinc or aluminum develop and seal porosity of thermal sprayed coatings. The finishing seal coat extends the life of the coating, including vinyl, PVBA, silicone and epoxy materials. It helps smooth the surface and resist dirt and other contaminants.

5.3.2.5 Inspection

Inspection and quality control is important in the thermal spray process. Specifiers often require regular production tests either on the actual work pieces or on production coupons. Bend testing may also be performed on production coupons. Significant quality control issues for thermal spray processes include the following:

- Anchor profile
- Adhesion
- Bend tests
- Surface finish (roughness)
- Dry film thickness (DFT)
- Porosity

5.3.2.5.1 Anchor Profile

An anchor profile of at least 2 mils (50 µm) and preferably 3 mils (75 µm) should be specified. Up to 6 mils (150 µm) can be tolerated without problems and may be beneficial in some instances. The anchor profile must be formed using a sharp angular grit. The adhesion will be much less with surfaces prepared using steel shot.

5.3.2.5.2 Adhesion

Adhesion is a significant indicator of long term coating performance. The adhesion of thermal spray coatings to a substrate depends to some extent on the application method. With aluminum coatings, adhesion strengths (bond strengths) of 13 to 20 MPa (2,000 psi to 3,000 psi) can be expected. Rather than test destructively, it is normal to specify a lower minimum value, 6894.8 kPa to 10342.2 kPa (1,000 psi to 1,500 psi) and suspend the test once the minimum test value is reached. Test dollies can then be removed without damage to the surface by heating the adhesive. Adhesion strength is normally greater with arc-spray application than with flame spray.

Testing actual adhesion can be useful to determine whether the adhesion is as good as the system design. These tests can be performed on representative samples prepared alongside the work piece. Sample coupons may be retained for reference purposes. To be truly representative, the sample coupon should undergo the same surface preparation treatment as the main work piece.

When using adhesion as a quality control factor, the test method and the required adhesion values should be carefully specified. The adhesion strength value depends on the equipment and test method used to make the measurement. ASTM D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers contains data on the reproducibility of the various pull-off adhesion test methods which are commonly used.

5.3.2.5.3 Bend Tests

A relatively simple adhesion test is produced by applying the thermal-spray coating to a sample coupon, which can then be bent around a narrow radius. Small coupons, generally (2 in. x 4 in. x 3/16 in.) are blast cleaned and coated, then bent over a 1/2 in. diameter mandrel. Minor cracking is considered acceptable, but major cracking or delamination indicates problems with the application process. Major cracking and delamination are considered failures.

The coupon should have a similar metallurgy to that of the substrate being coated, but should be thin enough to bend. Surface preparation and coating application should be identical to that used for the work piece.

5.3.2.5.4 Surface Finish

Surface roughness of the applied metallizing, between 1.2 mils and 4 mils (30 µm to 100 µm), is expected with arc-spray techniques. Research shows that the surface finish or roughness can be reduced by controlling spray distance, air pressure, and arc-spray voltage. Other factors, such as porosity, are considered to be more important, and good control of these parameters tends to minimize surface roughness. There probably is no value in trying to control this parameter by specification unless roughness is important for a specific reason. Inspection criteria in this area are difficult to define.

The application of a sealer coating helps smooth the surface and resists dirt and other contaminants, but the applicator will have difficulty achieving the same surface finish that can be obtained with conventional coatings.

5.3.2.5.5 Dry Film Thickness

Dry film thickness (DFT) of thermal spray coatings on steel can be measured by using conventional DFT gauges. It is difficult for the applicator to accurately control DFT, so careful and frequent measurement is required. Because accurate control of coating thickness is difficult to achieve and depends on applicator technique, DFT should be carefully specified, stating both minimum and maximum. Typical thickness is in the range of 4 to 12 mils for these coatings. Liquid applied sealer coats may be applied at similar thicknesses over the thermal spray material.

Porosity

Porosity of the thermal spray coating is critical to the coating's ability to protect its underlying substrate. The splatter technique of application results in an inhomogeneous coating. The porosity of applied thermal spray coating films varies with the application technique. Arc-spray processes produce films with greater density than flame spray techniques. HVOF will produce films of the lowest porosity.

The distance of the spray head from the substrate significantly affects porosity. An arc-spray distance greater than 6 in. (150 mm) increases porosity from 2to 14 percent.

The specification can refer to an acceptable level of porosity in terms of percentages. For example, the specification may state, "Porosity shall be less than 12 percent of the sample area when viewed in cross section." However, porosity is difficult to measure. Traditionally, random samples of coating cross sections are examined and physically measured by comparison with a grid. When seen under a microscope, the portion of the cross section that shows voids represents the porosity. This technique is useful when laboratory facilities are available and representative samples can be prepared for testing purposes. For site testing, the cross section method has the disadvantage of delayed results. Several days may pass before results are available.

5.3.3 Characteristics of Thermal Spray

5.3.3.1 Materials

A wide range of metals, including stainless steel, zinc, aluminum, tungsten carbide, and a variety of ceramic metals, can be sprayed in powder or wire form. Zinc, aluminum, and zinc-aluminum alloys are the most common corrosion control coating materials applied by thermal spray methods. They provide effective long term corrosion protection for steels in a wide variety of corrosive environments.

5.3.3.2 Corrosion Resistance

Thermal spray coatings function as barrier coatings, which isolate the substrate from the environment, and as galvanic coatings, which corrode in preference to the underlying substrate. A build-up of coating corrosion products gives added protection to both the metallic coating and the substrate. When used in conjunction with typical cathodic protection systems, thermal spray coatings reduce current demand. For maximum protection in atmospheric environments, thermal-spray coatings may be sealed with an organic topcoat.

Thermal spray systems may consist of the following:

- Sprayed base metal only
- Sprayed metal plus sealer
- Sprayed metal plus sealer plus topcoat.

A relatively thick metal coating without a sealer or topcoat provides the longest maintenance interval. While the addition of a sealer or topcoat may extend the service life of the metallizing, sealed or topcoated systems will require maintenance primarily for cosmetic purposes.

5.3.4 Advantages and Disadvantages of Thermal Spray

Thermal spray coatings offer the following advantages:

- Improved corrosion performance
- Increased initial costs
- Resistance to mechanical damage
- Suitability for immersion service
- Minimal hazardous waste disposal

5.3.4.1 Improved Corrosion Performance

Thermal spray coatings can provide corrosion protection to steel for fifty years or longer, depending on the environment. In atmospheric service, thermal spray coatings which are not topcoated will experience corrosion at some minimal rate, depending on the coating material and environment. Topcoating will generally extend this service life. However, the topcoat will probably need to be repaired to maintain its desired aesthetic quality.

5.3.4.2 Increased Initial Costs

Thermal spray coatings can increase the initial cost of coatings application, however, the long term costs can be reduced. The increased initial costs can be attributed to the slower production rates than other coatings, along with the requirement for a cleaner surface with deeper anchor profile. Cleaner surfaces/deeper profile increases the surface preparation costs. The costs can initially be higher due to the requirement for highly trained applicators and specialized equipment.

5.3.4.3 Resistance to Mechanical Damage

Thermal spray coatings have excellent resistance to mechanical damage, showing relatively little delamination in even the worst handling situations. Damaged areas, which are usually small, can be repaired with thermal spray coatings or with conventional coatings. Because topcoats are for cosmetic purposes only they can be repaired locally without affecting the integrity of the system. It is important to note that aluminum and zinc metallizing are relatively soft coatings which may be susceptible to wear and erosion. Both aluminum and zinc metalizing have been used on sea water immersed pilings with good success.

5.3.4.4 Suitability for Immersion Service

Thermal spray coatings are suitable for corrosion immersion service. Both thermals spray zinc, 85/15 zinc aluminum, and aluminum have been used to protect piling and other structural steels used in marine or brackish waters. Thermal spray aluminum has been used extensively to protect steel used on offshore platforms. The coatings provide barrier protection and localized cathodic (sacrificial) protection. The ability of thermal-spray coatings to resist mechanical damage is also important for immersion service. It has been calculated that an area coated with thermal-spray aluminum (TSA) could protect a structure in saltwater immersion for up to 30 years, even when up to 4% of the area was bare steel.

5.3.5 Health and Safety Concerns of Thermal Spray

The generation of dust and fumes during thermal spraying causes a significant health and safety concern. Aluminum dust can burn with aggressive flames and it may be explosive. Particles below 10 microns have a high explosive risk. Applicators need to avoid breathing dust and fumes at all times, and they must wear industry approved respirators to protect themselves. Zinc flu affects some operators who breathe in dust and fumes. It is a temporary illness with symptoms that are similar to a heavy cold. Normal healthy conditions can be restored after 24 hours of rest without long term adverse effects. Drinking milk reduces exposure to dust and fumes. All personal protective equipment (PPE) requirements need to be followed due to this dangerous health risk.

5.3.6 Uses/Applications of Thermal Spray

The following uses/applications are common for thermal spraying:

- Industrial atmospheres
- Bridges
- Marine atmospheres
- Ship Hulls
- Tank interiors
- Hot surfaces
- Extended service life

5.3.7 Standards for Thermal Spray

Additional information about thermal spray coatings are in the following standards and guides.

- NACE No. 12/AWS C2.23M/SSPC-CS 23, “Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and their Alloys and Composites for the Corrosion Protection of Steel.”
- AWS C-210 and MIL Standard DOD-STD-2138A (SH), “Metal Sprayed Coatings for Corrosion Protection Aboard Naval Ships.”
- ANSI/AWS C2.14, “Corrosion Tests of Flame Sprayed Coated Steels.”
- ANSI/AWS C2.16, “Guide for Thermal Spray Operator Qualification.”
- ANSI/AWS C2.18, “Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites.”
- AWS TSH, Thermal Spray Handbook (Practice, Theory, and Application).

5.4 Rubber Linings

Rubber sheet linings are classified in the coatings industry as thick barrier linings. They are made from various types of natural and synthetic rubber. Natural rubber is derived from latex obtained from Hevea trees and then coagulated with acetic or formic acid. Synthetic rubbers are man-made elastomers that demonstrate one or more of the properties of natural rubber.

Rubber linings are widely used as barriers to protect surfaces such as metal, concrete, and fiberglass from chemical attack, and abrasion. They are also used to contain certain chemicals and noncorrosive products.

Rubber linings can be manufactured to yield different properties for specific service applications. They are used in the storage and transportation of a variety of materials, including the following:

- Acids
- Certain alkalis
- Food chemicals and food products
- Selected solvents
- Specialty chemicals and other corrosive products
- Plastic pellets
- Clays

5.4.1 Types of Rubber

Rubber exists in natural rubber types as well as synthetic rubber types, and there are various different forms of those natural and synthetic rubbers.

5.4.1.1 Natural Rubber Types

Natural rubber is the polymer base for a large percentage of manufactured rubber lining products. Natural rubber consists principally of polyisoprene. In general, lining compounds based on polyisoprene are resistant to most inorganic chemicals with the exception of strong oxidizing agents. Resistance to organic chemicals is limited. Natural rubber is not suitable for use with hydrocarbons, halogenated hydrocarbons, mineral oils, many vegetable oils, and esters.

Three categories of natural rubber are:

- Soft
- Semi-hard
- Hard

5.4.1.1.1 Soft Natural Rubber

Soft natural rubbers generally demonstrate Shore Adurometer hardness values between 30 and 60. They are characterized by high levels of polymers and relatively low levels of fillers and reinforcing agents. Of the three natural rubbers, soft rubber offers the greatest flexibility, elongation, and accommodation to movement of the underlying surface.

Soft rubbers have the following properties:

- Good resistance to many corrosive chemicals, including food-grade phosphoric acid
- Excellent abrasion resistance
- Good temperature resistance up to 140°F (60°C)
- Good water resistance

Soft rubber linings are standard for tanks containing hydrochloric (muriatic) acid. Soft rubber is unique in that it forms a surface film that toughens slightly and retards acid penetration. Washing the film with water tends to disturb the film and soften the rubber.

5.4.1.1.2 Semi-Hard Natural Rubber

Semi-hard natural rubber, with a hardness range of 70 Shore A to 75 Shore A, is compounded with about 15% weight of sulfur. Higher sulfur content makes the rubber harder. The material may be mixed with acid-resisting fillers, rubber dust, accelerators, and limited amounts of plasticizers to produce a workable mass. The resulting mass can be kneaded, extruded, and/or calendered and then applied directly over tie gum. Tie gum enhances adhesion of the rubber to the substrate.

Semi-hard rubber resists to the same chemicals as soft rubber but may be used for stronger concentrations and at temperatures up to 180°F (82°C). This lining material may be used for

services that would otherwise require hard rubber, but the brittleness of the hard material cannot be tolerated.

Semi-hard rubber can be used in water-conditioning equipment and for protection against wet chlorine gas, strong acids, and plating solutions. These rubber compounds are sensitive to temperature changes and become very brittle at freezing temperatures. They are not suitable for some outdoor installations or in services in which wide temperature changes are anticipated.

5.4.1.1.3 Hard Natural Rubber

Hard rubber can handle highly corrosive solutions, such as concentrated HCl and wet chlorine gas at 200–220°F (93– 105°C). Generally, hard rubbers are used on rigid shapes of well-designed equipment that is not subjected to rapid temperature changes. Because of their low permeability to moisture, hard rubbers are often used in water-treatment facilities. They also offer good abrasion resistance. Hard rubbers range in hardness from 60 Shore D to 80 Shore D. Hardness Scales and Coating MaterialsCoating Materials compares rubber hardness measurements to those of some plastic materials.

5.4.1.1.4 Hardness Scales and Coating Materials

Hard rubber linings are normally produced by adding higher levels of sulfur to the soft-rubber formulations. However, some hard rubbers are produced with relatively low sulfur levels by incorporating various resins into the formulations.

5.4.1.1.5 Triflex (Soft/Hard/Soft) Construction

A soft/hard/soft, or triflex, construction is often used to form a sandwich film consisting of a soft natural-rubber base (tie gum), laminated to a semi hard or hard natural or ebonite center layer, and covered with a soft natural top coat. The base layer and top layer may be of the same formulation, but many topcoats have been specifically designed for given service situations.

Triflex products combine the excellent adhesion and thermal-shock resistance of the soft natural compounds with the superior resistance to permeation provided by the hard rubber center. These materials are used in combined abrasion and corrosion service, as in pickling lines, phosphoric acid service, and halogen acid (HCl, HBr, etc.) service. They also offer resistance to thermal shock and fatigue from flexing.

5.4.1.2 Synthetic Rubber

Types of synthetic rubbers include the following:

- Butyl rubber
- Chlorobutyl rubber
- Neoprene rubber
- Nitrile rubber
- Chlorosulfonated polyethylene (CSM [Hypalon†])

5.4.1.2.1 Butyl Rubber

Commercially available since the 1940s, butyl rubber offers exceptional resistance to gaseous diffusion, ozone, UV light, and aging effects and high heat. Butyl-rubber products see service in hydrofluoric acid, many oxidizing acids, water-service applications, and high-temperature (up to 200°F [93°C]) environments.

Butyl rubber is a very pliable, moldable material and is generally used in fittings and in other areas where sheet lining is not feasible. Butyl rubber is easy to vulcanize, but may require the use of activated acceleration systems and strict control to achieve the desired service life. Due to its cost, butyl rubber is not used as a sheet lining. However, it can be easily reacted with chlorine to produce chlorobutyl rubber, which is used as a sheet lining.

5.4.1.2.2 Chlorobutyl Rubber

Chlorination of the unsaturated sites on the butyl-rubber molecule produces a more reactive hydrocarbon polymer that is generally easier to process than butyl rubber. The chlorobutyl polymers accept a much wider range of vulcanizing systems. Chlorobutyl rubber can also be blended with small amounts of natural rubber to offer products with enhanced adhesion characteristics.

Chlorobutyl rubber has very low permeability and excellent chemical resistance. It is widely used in water boxes in the power-generating industry. Typically, it can be applied as thick as 0.5 in. (12 mm) over tie gum bonded to special adhesive primers. Chlorobutyl rubber is also used in flue-gas desulfurization (FGD) scrubbers, and for chemicals, such as sodium hypochlorite, super-phosphoric acid, and sulfuric acid.

5.4.1.2.3 Neoprene Rubber

Neoprene, or polychloroprene, rubber became the first synthetic rubber in commercial use in the early 1930s. It possesses many elastomeric properties similar to natural rubber and, when properly designed, offers superior resistance to heat, ozone, UV radiation, and oil. Most neoprene products have hardness between 40 Shore A and 70 Shore A, which is similar to the hardness range of soft and semi-hard natural rubbers.

Neoprene is a general-purpose material that is resistant to a wide range of physical and chemical conditions, including the following:

- Lubricating oils
- Gasoline
- Sulfuric acid 50% at 180°F (80°C)
- Strong hydrochloric acids and hydrofluoric acids at room temperature
- Sodium hydroxide (50% to 70%) at 200°F to 230°F (93°C to 110°C)
- Acid slurries

Several neoprene formulations are fire retardant and offer good service in salt-water environments.

5.4.1.2.4 Nitrile Rubber

Nitrile rubbers are produced from the copolymerization of butadiene and acrylonitrile. The physical properties of nitrile rubber are influenced by the percentage of acrylonitrile present. Nitrile can be compounded and vulcanized to form soft, semi-hard, and hard rubber compositions. The soft form is most common for lining applications.

Nitrile rubber has good resistance to aliphatic solvents — such as kerosene, naphtha, and mineral spirits — as well as animal, vegetable, and mineral oils. One of the most important performance characteristics of nitrile rubber is oil resistance. These materials are not recommended for use with phenols, ketones, strong carboxylated acids, aromatic hydrocarbons, and nitrogen derivatives.

5.4.1.2.5 Chlorosulfonated Polyethylene (Hypalon)

Hypalon[1] is the result of an effort to develop a vulcanizable, rubbery product derived from polyethylene. Although it is a chlorosulfonated polyethylene, it is regarded in industry as a form of synthetic rubber. Chlorosulfonated polyethylene (CSM) is available in different grades, which reflect the viscosity and chlorine content of the polymer. CSM polymers have been commercially available since the early 1950s and use standard vulcanizing technology to produce rubber lining material.

1. Trade Names

Hypalon is very resistant to weathering. It is also resistant to oxygen, ozone, heat, flame, tears, abrasion, oil, and grease. Hypalon has gained wide recognition in handling chromic acid (10%), hydrogen peroxide (30%), and sulfuric acid (50% to 75%). It is resistant to temperatures up to 200°F (93°C).

5.4.2 Application of Rubber Linings

The applicator and purchaser should meet to resolve specific details of the rubber-lining job prior to beginning the work. These details may include the following items:

- Inspection points
- Responsibility for correcting defects
- Method of vulcanization
- Shrouding plan, if necessary
- Brand and nominal thickness of specified lining material
- Acceptable repair methods and materials
- Acceptable number and size of repairs after vulcanization

Atmospheric conditions should also be defined to eliminate the possibility of condensation on surfaces to be lined. During surface preparation, the humidity level should be less than 90%. During adhesive application, the humidity level should remain at less than 90%, and the surface temperature should be at least 3°C (5°F) above the dew point. During application of the rubber lining, the humidity level and dew point requirements remain the same, and the surface temperature should be above 10°C (50°F).

The application process for rubber linings involves the following steps:

- Surface preparation
- Adhesive application
- Rubber-lining application
- Inspection and repair (if required) before cure
- Cure (vulcanization)
- Inspection after cure
- Repair (if required)

5.4.2.1 Surface Preparation

The primary requirement for any rubber lining project is that all vulnerable surfaces be accessible for lining installation. Surface preparation requirements are generally stricter than those required by many liquid-dispersion materials.

Typical surface preparation requirements for steel surfaces to be lined include the following:

- The steel shall be new, full-weight steel, free from structural defects
- The steel plate shall be flat, with no appreciable warp or buckle
- The steel should be free of galvanizing or other plating, oil, and grease
- The steel plate should have a minimum thickness and weight per square foot (e.g., a 0.19 in. [5 mm] thick steel plate should 10.2 lb/ft2 [51 kg/m2], and a 0.5 in. [13 mm] plate should weigh 20 lb/ft2 [100 kg/m2])

- Vessels must be braced to avoid bulging
- All welds should be solid and continuous, should be peened to eliminate porosity, and should be ground to remove sharp edges and high spots
- Edges and corners should be ground to a minimum radius of 0.13 in. (3 mm)
- All weld spatter should be removed

Metal surfaces to be rubber lined should be free of all oil, grease, dirt, old coatings, and other contaminants. Any visible oil or grease should be removed by solvent wash using a clean rag in accordance with SSPC-SP 1, "Solvent Cleaning." Surfaces contaminated with salt or chemicals should be high-pressure water blasted.

Metal surfaces to be lined should be blasted to white metal (NACE No. 1/SSPC-SP 5, "White Metal Blast Cleaning." In areas where blasting is not practical, grinding in accordance with SSPC-SP 11, "Power Tool Cleaning to Bare Metal," is acceptable.

Blasting profile should be uniform. Optimum profile is between 1.5 mils and 2.5 mils (37.5 µm and 62.5 µm). Although a profile higher than 2.5 mils (62.5 µm) is acceptable, it should not exceed 4.0 mils (100 µm).

During and after the blasting operation, high-pressure air is used to clean scale and grit off the surface prior to application of adhesive. Vacuuming or brushing with a clean, oil-free brush is also recommended to clean the blasted metal.

5.4.2.2 Adhesive Application

The primer coat of the adhesive system should be applied to the substrate as soon as possible after surface preparation is completed to avoid rust bloom and other surface contamination. If the surface becomes contaminated, it must be re-blasted. The type of adhesive, thickness of adhesive coats, and the minimum and maximum adhesive drying times are recommended by the rubber manufacturer. The minimum drying times depend on temperature and humidity. The maximum times reflect the time after which the adhesive coat needs to be reapplied.

Any dust on the surface must be blown, swept, or brushed away prior to application of any adhesive. Workers wearing clean, grease-free cotton gloves apply the adhesive by brush, roller, or spray. A work log is kept to record the time lapse between blasting and priming. The maximum time lapse between blasting and priming at 0–60% relative humidity is 24 hours and, with varied humidity, 8 hours.

The adhesive system for rubber linings is generally composed of a primer, an intermediate layer, and a tack-cement top layer. The particular adhesive products are specified by the rubber manufacturer. Certain adhesives are degraded by exposure to sunlight. All surfaces should be kept away from sunlight and, if adhesives are exposed to the sun, the manufacturer should be consulted before proceeding.

5.4.2.3 Applying Rubber Linings

Rubber linings may be applied and cured in a plant or in the field.

5.4.2.4 Plant Installation

The lining is unrolled, placed on a table, and cut to the required dimensions. When the lining requires pre-shrinking, it should be unrolled on the table and allowed to shrink prior to cutting to size. For complex shapes, the rubber should be cut to fit the contours with the least amount of stretch. Edges are skived at an angle of 30° or greater to aid in forming the seam. When joined, the edges of the lining material must fit precisely unless the specification calls for an overlap.

After cutting the sheet and just prior to installation, the side that will be in contact with the substrate is cemented with a coat of tack cement or other adhesive as required. Once the sheet dries, it is rolled up on a lint-free muslin cloth for transporting to the area to be lined. After the lining is properly positioned, it is rolled (generally by hand) to remove any bubbles or wrinkles.

Typically workers start in the center and roll out to the edges to ensure that no air is trapped behind the rubber. Stitches are used to flatten the seams, corners, and edges.

There are two general styles in making a seam:

Butt-skive joint with or without cap strip. See *Figure 5.8 Cap Strip*.

Overlap (open or closed skive). See Figure 5.9

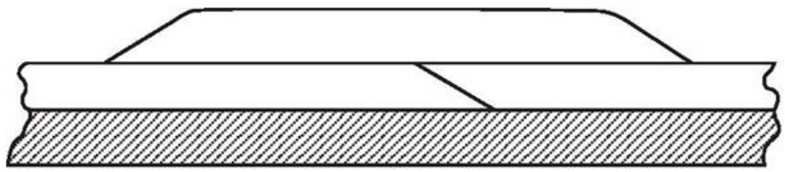


Figure 5.8 Butt Joint with Cap Strip

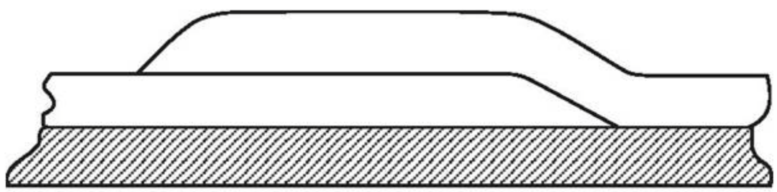


Figure 5.9 Closed Skive Overlap

The lining specification will indicate the proper seam style. Open skives are used with one-construction linings. Closed skives are used with multiple-construction linings to protect the underlying plies.

Where butt-skive joints are required, the lining sheets are skived at a 45° angle and mated together. The most common seam uses a 2 in. overlap with a closed skive. Seams should be in the direction of flow to prevent them from lifting.

5.4.2.5 Field Installation

Field lining with rubber is performed when it is not possible to transport the item to an autoclave. When lining in the field, tanks should be warmed to 55°F (13°C). In cold weather, tanks should be covered and heated. In general, equipment must be protected from the weather, and areas to be lined should be protected from direct exposure to the sun. Ordering and delivery of rubber-lining materials should be coordinated with job schedules to prevent long storage periods.

A typical field installation of a closed-top tank may proceed as follows:

After proper surface preparation, the tank walls, ceiling, and the floor area around the bottom corners of the tank are primed with the appropriate adhesive. The walls are lined first and the floor last.

Sheet rubber is applied to the walls with enough material to overlap onto the tank bottom. The top end of the rubber is overlapped onto the roof just as at the bottom.

The lined area is thoroughly rolled by hand to remove any bubbles or wrinkles. The joints at the top and the bottom are made away from the corners. When the walls and ceiling are finished, then the bottom is lined.

5.4.2.6 Curing (Vulcanization)

Rubber is cured by vulcanization, a process discovered simultaneously in 1846 by Charles Goodyear in the United States and Thomas Hancock in England. Vulcanization converts rubber

hydrocarbon from a soft, tacky thermoplastic material to a strong, temperature-stable thermoset material with unique elastic modulus and tensile properties.

The vulcanization process is a physicochemical (physical and chemical) change resulting from the cross-linking of the unsaturated hydrocarbon chain of natural rubber (polyisoprene) with sulfur and the application of heat. Unsaturation of a chemical compound is defined as the state in which not all of the available valence bonds along an alkyl chain are satisfied; in such compounds, the extra bonds usually form double or triple bonds, chiefly with carbon. Unsaturated compounds are more reactive than saturated compounds.

Natural rubber is blended with 3% sulfur, 1% organic accelerator, 3% zinc oxide, and certain fillers or reinforcing agents. It is cured in the presence of steam at temperatures of 250–300°F (125– 150°C).

All synthetic rubbers require vulcanization. In general, sulfur is used with the unsaturated polymers, while certain saturated polymers may be cross-linked with peroxides, metal oxides, or diisocyanates.

Three factors affect the properties of the vulcanized product (or vulcanizate):

- Percentages of sulfur and accelerator
- Temperature of the curing process
- Time of cure
- Curing can take place in a rubber-lining plant or in the field.

5.4.2.7 Plant Cure

Curing is generally performed in an autoclave with live steam at about 50 psi (345 kPa) and 250–300°F (125–150°C). Curing is a time-temperature relationship: the lower the temperature, the longer the cure time, and the higher the temperature, the shorter the cure time. Internal steam cure or water cure methods may also be used for vulcanization.

5.4.2.8 Field Cure

Once the tank is lined and ready for cure, an exhaust steam line with a swivel elbow is placed in the tank and the tank shrouded to retain the heat. Live steam is introduced into the tank. Moving the elbow circulates the steam. The steam volume is determined by the vessel size and is specified by the applicator. The field-curing process is often called exhaust cure.

In the curing cycle, it is possible to achieve at least a 30°F (17°C) differential between the outer steel wall and the steel at the rubber interface. The cure process may require 24–36 hours.

5.4.3 Inspecting Rubber Linings

The following steps can be taken to ensure the rubber lining meets the requirements of the specification:

- Inspection of equipment and materials upon receipt
- Inspection prior to blasting
- Inspection after blasting
- Priming and cementing
- Rubber-lining application
- Pre-cure inspection
- Curing
- Post-cure inspection

- Repair after cure
- Finishing
- Pre-shipment inspection

Unique aspects of these steps are further discussed below.

5.4.3.1 Inspection before Cure

The rubber lining should be visually inspected for the following items:

- General appearance of the surfaces, wrinkles, bubbles, pinholes, physical damage
- Looseness and uniformity at all splices and seams
- Shadow areas where trapped air has formed high spots. These are detected by using a light near the surface

A high-voltage holiday test at the rubber manufacturer's recommended voltage is passed over the lining to detect pinhole leak. Refer to NACE SP0188, Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates for detailed operating procedures. A pinhole or leak shows up as a white or blue arc jumping from the test probe to the metal surface through the leak in the lining. A violet discharge occurs over a leak-free lining. All leaks are circled with marking chalk for repair prior to cure.

Neoprene rubber and some synthetics with high graphite content require lower voltage to eliminate the risk of burning holes in the rubber.

Only individuals qualified to operate holiday testers should use them to inspect rubber linings. Inexperienced personnel may cause damage to the rubber lining or incur personal injury.

5.4.3.2 Repair before Cure

Any areas found unacceptable before vulcanization are repaired by solvent wiping, applying tack cement, and overlaying with stock rubber. The defective rubber may also be removed and new rubber applied to the cut-out area. The inlaid rubber is overlapped with an additional piece of rubber, which is extended 1 in. (2.5 cm) in all directions beyond the edges of the inlay. Any trapped air is removed by using a hypodermic needle. The area is re-stitched. Repairs made to uncured rubber that are vulcanized with the original lining are not considered to be repairs or patches. They are deemed to be part of the original system.

5.4.3.3 Inspection after Cure

All lined areas should be thoroughly inspected after cure in the same manner as prior to cure. The lining is checked visually for wrinkles, bubbles, and any other unusual visible physical defects, and holiday testing is performed with a high-voltage spark tester. In addition, the cured rubber sheet is checked for hardness in accordance with ASTM D 2240, "Standard Test Method for Rubber Property–Durometer Hardness." Hardness readings are recommended by the rubber manufacturer.

Adhesion tests may also be performed on cured samples in accordance with ASTM D 429, "Test Methods for Rubber Property–Adhesion to Rigid Substrates." A calibrated spring scale is used. An average adhesion of less than 4.5 kg/cm (25 lb/in.) is cause for rejection. If the rubber breaks during testing, the adhesion is also considered inadequate.

5.4.3.4 Repair after Cure

Damaged, defective, or non-adherent linings must be repaired. Repair procedures may vary according to the specific manufacturer's recommendations but normally include the following steps:

1. Cut out all defective lining (bubbles, loose lining, etc.)

2. Buff about 1 in. (2.5 cm) of the sound lining on all sides so that it will properly bond to the repair patch
3. Grind the exposed metal to white metal in accordance with SSPC-SP 11
4. Apply the adhesive system recommended by the manufacturer. Cut a rubber inlay to fit the repair area. Cut another piece of rubber with a 1 in. (2.5 cm) extension in all directions to cover the inlay rubber. The area around the exposed metal, the top and the back of the inlay rubber, and the back of the overlay layer are cemented with tack cement
5. Roll the repaired and overlaid areas with rollers and stitchers
6. Cure, either by applying topical curing compounds for chemically cured rubber or by using steam for steam-cured rubber
7. After cure, inspect the repair for defects and hardness

5.4.4 Characteristics of Rubber Linings

Hardness is an important characteristic of rubber linings, and they range from soft natural rubber to semi-hard to hard rubber. Soft natural rubber has a Shore A Durometer between 30 and 60. It has high levels of polymers and low levels of fillers. Semi-hard rubber has a Shore A Durometer between 70 and 75, with a high sulfur content (15%) and fillers, which make rubber harder. Finally, hard rubber has a Shore D Durometer between 60 and 80, and it is formulated with high sulfur levels or resin incorporation.

5.4.4.1 Causes of Failure

In general, rubber linings will last the life of the process equipment subject to specific limitations on application quality. Ninety-nine percent of all bonding failures are due to improper surface preparation. However, rubber linings can fail for a number of additional reasons, including swelling, chemical attack, temperature, chemical concentration, contamination, and a dynamic environment.

5.4.4.1.1 Swelling

Swelling is the result of the absorption of working fluid into the elastomeric matrix causing a volumetric increase in the rubber lining. The strain induced in the polymer network by the increase in volume makes the lining susceptible to mechanical damage. Non-reinforcing fillers that increase resistance to swelling in many fluid applications can be added to the rubber compound during formulation.

Cross-link density, normally associated with cure but also a function of formulation profoundly influences a rubber lining’s ability to resist swelling. Tighter cures produce higher cross-link density, which prevents the absorption of working fluid. A rubber lining that is totally immersed will suffer greater degradation from swelling than a lining exposed to one face of the material.

5.4.4.1.2 Chemical Attack

Whereas swelling is an inert physical change to the polymer network, chemical attack is a degradation of the polymer structure. The polymer structure may be degraded in the following:

- Reduction in the length of the polymer backbone
- Separation of the cross-links between polymer chains
- Alteration of the molecular structure
- Liberation of molecular components

Testing is required to predict the resistance of rubber linings to chemical attack. Many years of test data are available. Past performance of rubber linings in a variety of service conditions provides invaluable insight for product recommendations in particular applications.

5.4.4.1.3 Temperature

Temperature is the external service condition that most greatly affects rubber lining materials. Maximum low and high temperature, working temperatures, temperature excursions, thermal shock, rate of heat transfer, and insulation are all temperature factors that can affect the service life of a rubber lining.

The rates of chemical attack, swelling, and permeation increase at higher temperatures. Low temperatures can cause embrittlement and induce crystal formation. All temperature factors of the service condition must be considered when selecting a rubber lining material for application.

5.4.4.1.4 Chemical Concentration

The concentration of the chemicals that will come in contact with the rubber lining must also be considered in lining selection. However, higher concentrations do not always lead to greater reactivity. Although many materials are more reactive in higher concentrations, some materials are more reactive at lower concentrations. For example, a process material in vapor phase can become significantly more reactive than the same material in solution. In addition, a material's insolubility or specific gravity may create localized concentration-cell corrosion, which can severely shorten service life.

5.4.4.1.5 Contamination

Foreign materials introduced into the process stream can have catastrophic effects on rubber lining material. Hydro-carbon solvents, alcohols, and ketones are common industrial fluids that can shorten the service life of rubber linings. Also, cycling different materials through the same lining environment can create contamination through chemical reaction. Identifying possible contaminants or contamination that may result from chemical reactions in the lining environment will help in the selection of an appropriate lining system.

5.4.4.1.6 Dynamic Environment

Few rubber-lining applications are static in nature. The sun can cause outdoor storage tanks to grow and shrink. Rail cars can undergo hogging (bending under load) and vibration. Pipes carrying slurry are continually abraded by the flow of the fluid.

The dynamic effects of the service environment are crucial in rubber lining selection. They can increase the demands placed on a material to tolerate the service conditions of a particular application.

5.4.5 Advantages of Rubber Linings

Soft rubber linings have excellent chemical resistance, excellent flexibility and elongation, and good temperature resistance (up to 140^0 F or 60^0 C). Semi hard rubber linings have excellent chemical resistance and good temperature resistance (up to 180^0 F or 82^0 C). Semi hard rubber linings are also resistant to wet chlorine gas and plating solutions. Hard rubber linings handle highly corrosive solutions such as concentrated HCL. They also have good temperature resistance (up to 220^0 F or 105^0 C) and low permeable to water.

5.4.6 6 Uses / Applications of Rubber Linings

- Railroad tank cars
- Truck tanks
- Barge tanks
- Reaction towers
- Process tanks and vessels
- Filters
- Flue gas desulfurization units Fume stacks

- Agitators
- Troughs
- Blowers and fans
- Crystallizers and sewers
- Pump shells and casings
- Rotors
- Chutes, hoppers, and conveyors

5.4.7 Standards for Rubber Linings

The following standard applies to rubber linings: NACE SP0298 Sheet Rubber Linings for Abrasion and Corrosion Service.

5.5 Glass Linings

5.5.1 Types of Glass Linings

Three types of glass that exhibit high corrosion resistance are used in the chemical process industry for severe chemical applications:

- High-silica — The most acid-resistant glass; not bondable to a metal substrate
- Alkali-silica — Can be fused to metal; widely used in glass-lined chemical process equipment
- Glass-ceramic (crystallized glass) — Can be fused to metal; useful in abrasive applications

The glasses used for linings are combinations of metal oxides, such as silicon, calcium, aluminum, potassium, and cobalt. Silica is the primary composite of glass, and the other oxides are added to impart a variety of corrosion-resistance properties. For example, zirconium provides alkali resistance, while cobalt oxide promotes adhesion to the substrate and gives the glass a blue color.

5.5.2 Application of Glass Linings

There are three types of glass products that are applied to metal substrates: frit, slip, and dusts.In order to apply the glass lining, following metal part fabrication, the metal to be glass lined is placed in a furnace, heated to 1,550°F (840°C), and then removed from the furnace to cool in air. The annealing (heating) process relieves stresses introduced in the metal by welding and fabrication. Heating also burns off any grease or oil on the metal surface.

Subsequently the metal substrate is grit blasted to remove furnace scale and oxide. Although adhesion between glass and steel depends mainly on the formation of a chemical bond, roughening the surface promotes a good mechanical bond between the glass and steel.

Four methods are primarily used to apply glass to metal:

1. Spraying — the slip is sprayed onto the clean metal surface and allowed to dry. Once thoroughly dry, piece is placed in a furnace and the coating fused to the metal. Subsequent glass coats may be applied and fused to each other.
2. Spray dusting — the piece is first sprayed with the glass slip; with the slip wet, glass dust is applied to the surface. The dry dust partially absorbs the water in the slip, causing the slip to adhere to the surface. With this method, thicknesses of 0.2 in. (5 mm) are usually applied per coat.

3. Slushing — the piece is either dipped into a container of slip or slip is poured over the metal surface. The dried coating is then fired in a furnace.
4. Hot dusting — Glass dust is sifted onto a preheated metal surface that has a ground coat. The piece is immediately returned to the furnace so the glasses fuse to each other.

Glass firing temperatures range in accordance with the following:

- Glass ground coats: 1,600°F to 1,700°F (870°C to 930°C)
- Glass cover coats: 1,500°F to 1,580°F (820°C to 860°C)

This process promotes fusion between the metal and coating, and it incorporates compressive stresses in the glass. The furnace environment controls the following issues: inert gases prevent rapid oxidation of base metal and low dew point reduces number of large bubbles in the glass coating.

5.5.3 Characteristics of Glass Linings

Glass linings have been used in the chemical process industry for years in chemical reactors, storage tanks, piping, and other harsh exposures. Glass linings are resistant to most corrosive substances, even under severe thermal conditions. The degree of resistance is related to the composition of the glass, the composition of the underlying metal, the service conditions, and the thickness of the glass lining.

Glass linings 40 – 90 mils thick (1.0–2.3 mm) provide outstanding resistance to a wide variety of acids in extreme process conditions. With the exception of hydrofluoric acid and hot, concentrated phosphoric acid, all common mineral acids can be handled continuously at temperatures of 300–350°F (150–180°C). The velocity and phase, i.e., liquid or vapor, may influence the corrosion rate.

Glass linings are less resistant to alkali conditions. As the alkali concentration increases, the glass corrosion rate also increases. In addition, temperature limits are more defined for glass linings exposed to alkaline solutions. In general, the higher the pH of the solution, the lower the temperature limits for the glass lining. The corrosion rate of alkaline solutions is a function of the pH, the specific reaction, the influence of other dissolved substances, and agitation. Product velocity or slight contamination, such as tap water in sodium hydroxide, can also affect the corrosion rate.

5.5.4 Disadvantages of Glass Linings

The following causes of failure are disadvantages of using glass linings:

- Hydrogen in steel
- Equipment design
- Equipment handling and welding
- Operational parameters

Hydrogen in steel must escape during the heating process or the glass can spall. The design of the equipment to be coated must have a consistent thickness with no sharp edges. Improper support, rough handling, and weld spatter can also create glass coatings failures. Finally, operational parameters must be strictly managed to ensure they do not cause failure in this specialty coating. Examples of operational parameters include mechanical shock, excessive pressure, sharp blows, thermal shock, cavitation, and low dielectric constant materials.

5.5.5 Uses/Applications for Glass Linings

Glass linings have been used in the chemical process industry for years. The following list describes common uses/applications:

- Chemical reactors
- Storage tanks
- Storage vessels
- Pipes and fittings
- Heat exchangers
- Columns
- Dryer blenders
- Wiped film evaporators
- Valves

5.6 Fiber Reinforced Plastic (FRP)

Fiberglass-reinforced plastic (FRP) is composed of inert chopped glass or synthetic fibers and a resin (e.g., polyester, vinyl ester, or epoxy). FRP can be used for corrosion protection, abrasion resistance, or to repair tanks, concrete structures, or other items that have been damaged by chemical attack. The fiber arrangement in the resin minimizes permeation of liquids and vapors through the coating, establishing a barrier to protect the substrate. FRP is a popular choice to repair badly pitted and otherwise corroded vessels. It can be used as a substrate as additional FRP layers are added to build thickness on the inside of a fiberglass tank.

The term laminate describes a system that is composed of several layers of reinforcing materials saturated with certain resins. Figure 5.10describes a representative system. Laminate systems may be applied in thicknesses ranging from 60 mils to 250 mils (1.5 mm to 6.25 mm), depending on the particular service requirements.

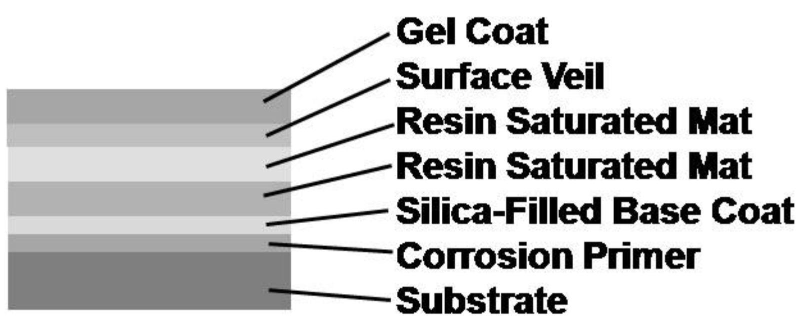


Figure 5.10 FRP Coating System

The chemical resistance of a fiberglass reinforced system is provided by the resin. Surfacing veils control the thickness of the resin layer and give strength to the most critical part of the corrosion barrier. The interior surface contains 90% resin and 10% veil material. Surfacing veils can be made from monofilament glass or polyester fibers.

5.6.1 Application of FRP

5.6.1.1 Metal Substrates

5.6.1.1.1 Surface Preparation

Apply FRP to clean and relatively smooth surfaces. Steam clean or wash the metal with 1% sodium triphosphate to remove grease, oil, and other contaminants. When the surface is dry, grit blast it to a bright metal finish. Do not wipe the surface with solvent, but brush or vacuum to remove abrasive dust. Fill pits, chamfer corners, and grind edges to ensure complete surface preparation.

5.6.1.1.2 Priming Surface

Brush-coat the clean prepared surface with a primer, which seals the surface and serves as a base for the FRP. When the prime coat is dry to the touch, check the surface with a test patch to make sure that it is able to accept a secondary bond (FRP layer). If FRP application is delayed, cover the primed surface to protect it from contamination. If the delay is longer than three days, the surface may require light re-blasting.

5.6.1.1.3 Lining application

Cut two layers of chopped strand mat and two layers of surfacing veil so the full liner thickness can be applied in one lay up. Apply the resin to the primed surface with a brush or roller, and then lay a chopped strand mat over the resin. Roll the chopped strand mat with a serrated layup roller until all air bubbles have been removed. Repeat the process until two bubble-free layers of chopped strand mat have been applied. Using the same sequence of operation, add subsequent layers of surfacing veil with resin. When applying FRP in layers, the required time intervals specified by the manufacturer between applications of layers must be observed to ensure proper coating of each layer.

In some applications, the fiberglass material may be applied by using of a chopper gun. Some spray units are capable of simultaneously applying a two-component coating with chopped glass fibers. Separate components are sprayed from an external mix gun, while glass roving (rope) fed by an air motor is chopped or shredded into small pieces by a chopper gun fitted inside the gun body. The coating components and the chopped glass fibers are combined just in front of the gun and propelled onto the surface. The sole purpose of the chopper gun is to shred or chop the glass roving into small pieces. These small pieces of fiber then become randomly dispersed in the coating and act as reinforcement to the mixture.

A top coat, sometimes called a gel coat, is applied over the final reinforcing layer as a sealer. The gel coat consists of the unreinforced resin mixture. Gel coats for vinyl ester and polyester resins usually contain a small amount of paraffin wax, which floats to the surface during cure. The wax layer helps prevent oxygen from retarding the cure of the resins. Complete cure of the resins is important to FRP performance. Wax top coats should be used as the final coating of all secondary layups and on all repairs of areas exposed to a corrosive environment.

5.6.1.1.4 Inspection and Repair

Throughout the application process, adequate inspection and repair techniques must be accomplished, including inspecting for defects, holiday (spark) testing, hardness testing, and repair procedures. Inspection should look for voids, dry glass, or exposed fibers. Bare threads may result in wicking, which draws the contents of the vessel into the coating system. Holiday testing should be performed after the gel coat cures. It should only be performed before the gel coat cures if it contains waxes that may interfere with repairs. Hardness should be measured before gel coat application. Finally, repair procedures include grinding as required to eliminate defects, and building FRP to the original thickness.

5.6.2 Disadvantages of FRP

The following list describes causes of failure in FRP coatings:

- Air bubbles/voids - air entrapment in / between plies; caused by poor or dirty surface or improper rolling during lay-up
- Blisters - rounded elevations of the laminate surface; caused by too rapid cure or moisture in resin, filler, or glass
- Impact cracks - separation of material through entire thickness; impact, insufficient reinforcement, or high resin concentration in one area
- Crazing - pattern of fine cracks on or beneath surface; caused by isolated resin-rich area, impact, or temperature differences, wetting/drying cycle, and resin shrinkage
- Delamination - separation of layers; caused by poor glass saturation, dirty surface, or a higher glass content than specified

5.6.3 Uses/Applications of FRP

The following list describes common engineering uses for FRP linings:

- Corrosion protection
- Abrasion resistance
- Reinforce concrete structures
- Repair badly pitted or otherwise corroded structures

Other uses/applications include:

- Tank linings and tank bottoms
- Water lines and condensing water systems (power plants)
- Ducts
- Scrubbers
- Stacks (exhaust gas)
- Pre-fabricated sumps and trench liner or inserts (intimate contact but not bonded)

5.6.4 Standards for FRP

The following joint standard applies to FRP linings: NACE No. 10/SSPC-PA 6 Fiberglass-Reinforced Plastic (FRP) Linings Applied to Bottoms of Carbon Steel Above ground Storage Tanks.

Chapter 8: Coatings Selection

OBJECTIVES

Upon completion of this training material, you will be able to:

OBJ. 8.1: Identify and determine coating properties which are important in a specific coating application

OBJ. 8.2: Understand how specific engineered properties will affect a coating Engineered Properties of Coatings

OBJ. 8.3: Use data from literature, case history and failure analysis to select and specify a coating

This chapter will deal with the process of selecting the right coating for your specific application. Choosing the correct coating for your application is the first step in a successful coating project. Improper selection of coating can lead to premature failure of the coating system and will inevitably increase maintenance costs. When selecting a coating system for a specific service it is important to consider several things:

- The goals and objectives of the coating system
- Performance requirements
- Desired engineered properties
- Other considerations

Taking all of these things into consideration prior to selecting a coating system will allow you to determine the correct coating system.

8.1 Coating System Goals and Objectives

8.1.1 Goals

The first step in determining which coating system is best for your current project is to set goals for the coating system. The exercise of thinking through the coatings project and setting goals will help determine which properties are necessary, which could be seen as nice to have, and which properties are not required.

To begin the goal setting process ask basic questions and be specific with the answers.

- What are we trying to accomplish?
- Why are we coating this item?
- What would happen if this item is not coated?

This information establishes the basis for the performance goals.

While goals are what you want out of the coating system, the other part of the equation is objectives. Objectives are specific and measurable performance targets for coatings which help you meet your goals.

Long lasting and best possible aesthetic appearance, long term corrosion control, and the complete elimination of any immediate corrosion consequences are desirable goals, but these do not represent objective criteria. Consider maintaining color and gloss. While most manufacturers will offer a coating with “long lasting” retention of color and gloss, we fall short because of the ambiguity in what “long lasting” really means. Be specific, if you know what change in color and gloss will constitute a “failure” of the coating system, set your objectives around that specific criterion.

8.1.2 Objectives

Again, objectives are specific and measurable performance targets for coatings which help you meet your overall goals. Objectives will most often include detailed information on performance requirements and engineered properties.

Aesthetics are a main reason for recoating. Among the aesthetic properties is color. The coatings ability to maintain at a certain color state for a period of time is its ability to withstand color change. Color change is often measured in ΔE, which is change of L*a*b color units, and is measured accordingly. An example objective for color steadfastness would be: "A change in color (ΔE) of less than 2.0 units over a period of 1.5 years."

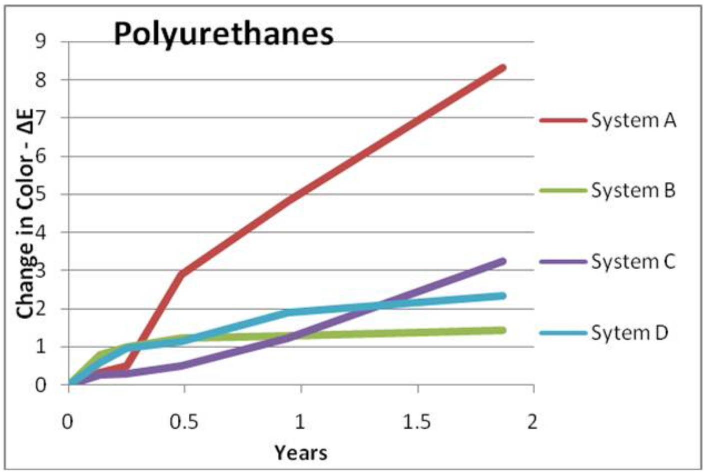


Figure 8.1 Change in Color over Time

Objectives can also be helpful within the specification to specify which coatings will be acceptable based on the coatings properties and performance.

The following example describes coating performance as an objective. Coating failure (or rusting) over time data can be used as an objective.

Consider that you are working for a customer trying to make a coating decision. The one objective that your customer has in coating his cargo hold is that the coating has a maximum allowable coating loss of 30% over a 10 year period. You are considering several coating systems. Among these is "Coating X". Using Figure 8.2 "Coating X" performance as a function of coating loss over time, would this be an acceptable coating for your customer?

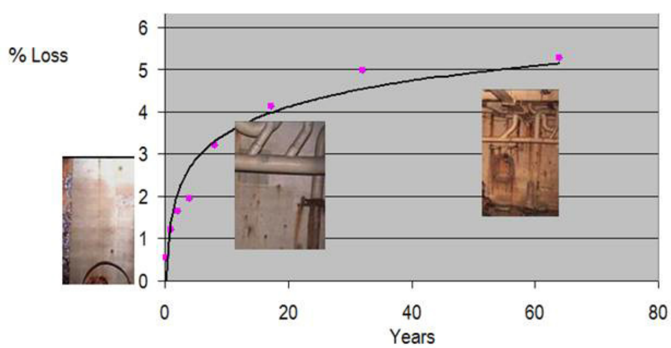


Figure 8.2 Coating Failure over Time

The answer is no. From the chart, we can see that the percent coating loss at 10 years is somewhere around 35%. However, there are a lot of things about this data that we do not know, which makes it hard for us to make an educated decision.

Additional considerations include the conditions that this coating was subjected to, and the relationship of those conditions to the customer condition requirements presented.

What we learn from this situation is that we need to be specific in our objectives. Put in as much detail as necessary.

Rather than an objective of "maximum allowable coating loss of 30% over a 10 year period," a better objective includes "maximum coating loss of 30% over a 10 year period when exposed in accordance with test method B," where test method B is clearly defined and documented.

Now that we have discussed goals and objectives and know the need for performance requirements and engineered properties, we will further discuss these in detail and how they can affect coating selection.

8.2 Coating System Performance Requirements

Performance requirements often focus on survivability over a period of time or in a particular environment. Determination of specific performance requirements will depend on how the coating is to be used.

Examples of performance requirements include:

- Service Life Longevity
    - Resist chemical attack
    - Maintain product purity
- Environmental Conditions
    - Atmospheric
    - Immersion
    - Chemical
- Aesthetics
    - Color
    - Gloss
    - Resist staining
    - Remain intact (no peeling, etc)

8.2.1 Performance Data

When choosing a coating to meet particular performance requirements, it is often useful to use coating performance data. This data can come from several different forms and from several sources, such as:

- Case Histories
- Manufacturer's Data
- Independent Testing
- Technical Literature
- Failure Analysis

Each of these can be a good source of information if you are selective and take time to understand the information you are being provided. As with any type of data, it is important that you compare like types of data. For instance, if you find adhesion data for coating "Uberstick" after it has been immersed in water for 5 years and you are really impressed with its performance, take the time to

figure out what type of water it was immersed in, what the substrate was, and what application conditions existed. There can be a huge performance difference between salt water and fresh water. Also, see if the conditions are consistent with the parameters you are trying to meet.

No matter where you are getting data from, unless it is your own data, do not rely on single data source. Remember data can be manipulated to be misleading. Finally, be aware that data can be subject to multiple interpretations.

8.2.1.1 Case Histories

Case histories can provide you with fairly accurate real time data of how a coating performs. When accessing the case history data, it is important to have an understanding of the entire history of the project. Case histories are advantageous because they provide real time data and situational coating performance data; however, the lack of specific information can prove to be a disadvantage.

Important factors to take into consideration when determining the relevance of case histories include:

- Location and environment in which the coating performed
    - Weather (temperature, humidity, rainfall, sun exposure)
    - Proximity to other detrimental objects (bodies of water, heat sources, chemicals/fall out from smoke towers)
- Coating application
    - What were the specification requirements and was the coating up to specification?
    - Any departures from the specification (poor surface preparation, out of range film thickness, missed overcoat windows, etc.)?
- Maintenance
    - Was routine maintenance performed?
    - When/what was typical maintenance for the coating system?
- Frequency of inspection
    - Was the coating inspected frequently for failure?
    - Simply knowing a coating failed after 20 years doesn't mean much if nobody looked at it until 20 years after it was installed.
- Definition of failure/why the need to recoat?

Case histories can also be used to determine situations for which you should not use a coating. This will be discussed further in the failure analysis section.

8.2.1.2 Manufacturer's Data

Manufacturer's data is a good place to start when looking for a coating to meet your performance requirements. Data is typically presented in a standardized fashion so that you can quickly determine if this is indeed the right coating for the application. Be careful about quick glances. Even though the company is presenting data, it is still considered marketing material.

Most data presented within a manufacturer's data sheet has been obtained through some sort of standardized testing. When comparing various data values between coatings make sure that the test methods used to obtain the data were similar. It is important to recognize that the standardized testing is typically performed under laboratory conditions, which may not be representative of the real world.

Finally, talk to the manufacturer's technical representative. While they have an obvious bias toward the products which they represent, the manufacturer's technical representative generally has a broad experience base. Reputable manufacturers will provide helpful guidance in selecting the best of their systems.

The information provided within the manufacturer's data sheet will help you to narrow down your coatings choices. Once you narrow down your choices, it is good practice to look elsewhere for additional information so you can make the best decision based on more than one source.

8.2.1.3 Independent Testing

Independent testing is not always a feasible option, but it can lead to the best performance data for your situation. Independent testing is usually performed for high cost projects, projects where a lengthy service life of a coating is necessary, or for projects where there is little to no performance data available.

Typically with independent testing you would consult a laboratory or exposure site and design an exposure test based on your needs. Unfortunately, this is often a timely process. Real time data will take years to obtain, and there is always some level of uncertainty when establishing a correlation between accelerated testing data and real time data. The positive aspects of independent testing are that you can choose the specific coatings, configurations, exposures and length of data collection.

This data will be tailored to your specific situation, and at the completion of testing, you will be better prepared for how your coating is going to act. This will allow you to think ahead to maintenance and replacement cycles.

Accelerated testing is a method of independent testing. You should refer to product data sheets first, and request accelerated testing only if the product data sheets do not have the required information available. Accelerated testing data is used regularly within the industry to illustrate coating performance; however, there are several benefits and shortcomings associated with accelerated testing.

Accelerated testing benefits:

- Performance data in a short period of time
- Controlled conditions

Accelerated testing shortcomings:

- Accelerated data may not provide a good correlation to real-life data
- Accelerated testing is an extremely harsh environment, the likes of which a coating will seldom see in the real world

Examples of accelerated testing for weathering conditions include light effects, moisture effects, heat resistance, and wear resistance, each with their own set of accelerated tests. Light effect tests include QUV (A and B), xenon-arc, and weather-o-meter tests, while moisture effect tests are captured using humidity cabinets, salt-fog testing, and immersion. In the case of heat resistance, fire exposure, smoke exposure, and high temperatures are tested, and wear resistance is track tested and strength (fatigue) tested.

8.2.1.4 Technical Literature

Technical literature is often useful in determining how a coating is going to perform in a certain circumstance. There is a lot of information available through a number of resources from highly technical academic studies to practical documented case histories. Be sure to scrutinize the information and do not necessarily believe everything you read. When using information from technical literature, there are several things that you need to consider:

- What exactly are the authors telling me?
- What are the experimental parameters that they are using? Are these parameters relevant to my task?
- Do I know enough to make a decision based on the presented information?

Collecting and combining information from several technical literature sources can be more beneficial than the information provided in a single paper. The key is to make an informed decision.

8.2.1.5 Failure Analysis

A failure analysis is performed to identify the cause of a coating failure. This information can be particularly useful in determining which coating to select for your service. The data presented in a failure analysis will typically contain the length of service that the coating was able to withstand along with detailed mechanisms of failure. The mechanisms of failure are typically broken down into:

- Physical causes
- Human causes

Physical causes could be due to environmental conditions, the location or operating conditions of the structure.

An example of a physical failure includes highly cross-linked coatings that tend to be very inflexible. If a highly cross-linked material was applied to a steel beam which flexed and vibrated often, the material would eventually crack causing a physical failure.

If your coating job required painting a flexible steel beam, you could learn from the failure analysis and choose a material with a less cross-linked chemistry.

The key to successfully using data from a failure analysis is to relate failure situations and causes to your project at hand.

8.3 Engineered Properties of Coatings

Within a coating, there are several properties which can be controlled through modifications to the design/chemistry of the coating. We call these engineered properties. Engineered properties enable us to get the desired coating qualities we need for a specific job.

Examples of engineered properties include:

- Adhesion
- Abrasion resistance
- Anti-fouling/foul release
- Chemical resistance
- Color
- Corrosion control
- Fire inhibition
- Flexibility
- Gloss
- Hardness
- Rapid cure
- Temperature resistance

We will discuss each of these engineered properties in further detail and how they affect the coating.

8.3.1 Adhesion

Adhesion is defined as the ability of a coating to adhere to a substrate. There are several items which will affect the ability of a coating to adhere to a substrate. Among these include:

- Hydrogen bonding
- Chemical bonding
- Enhanced surface area
  - By physical means such as abrasive blasting
  - By chemical means such as pretreatments and conversion coatings

Enhancing the surface area of the substrate will also increase the adhesion properties of a coating. This can be done through physical and chemical means. Physically, the surface can be abrasively blasted or roughened to create a greater linear surface area.

After abrasive blasting there is additional surface area to which the coating can bond to – this leads to greater adhesion. Chemically the surface area can be enhanced through the use of pretreatments and conversion coatings. Conversion coatings consist of a compound of the surface metal, produced by chemical or electrochemical treatments of the metal. Examples include chromate coatings on zinc, cadmium, magnesium, and aluminum and phosphate coatings on steel. Acid etching and other forms of pretreatment coatings will change the surface chemistry of the substrate and will promote adhesion.

8.3.2 Abrasion Resistance

Abrasion resistance is the ability of the coating to withstand outside mechanical friction such as rubbing, scraping or erosion. Abrasion resistance and hardness are very similar properties in their chemical mechanisms.

Chemical properties which affect the abrasion resistance of a coating include:

- Prevalence of cross-linking within the polymer
  - Greater amount of cross-linking yields a harder surface
- Glass transition (Tg) temperature
  - As the Tg of the coating decreases so does the hardness of the coating
- Pigment choice
  - Choosing pigments which are generally hard will increase the overall hardness of the coating

8.3.3 Anti-fouling and Foul Release

Anti-fouling coatings are important in several industries, but are most commonly referred to within the shipping industry. An anti-fouling coating is designed to prevent the accumulation of a substance or organisms onto the surface of the coating. The accumulation of organisms on the surface of a coating, such as barnacles, is referred to as biofouling. Accumulation of fouling can cause a myriad of problems including limiting the flow through intakes and pipelines as well as causing a significant reduction in speed of a vessel which will lead to increased fuel and maintenance costs. Through the use of anti-fouling coatings we hope to avoid those significant problems and costs.

Controlling fouling on a ship can be accomplished by the use of the following types of coatings.

- Leaching
- Ablative (self-polishing)

Each of these types of coatings has a different mechanism of protecting the surface from accumulation.

In a **leaching** type coating, some sort of toxin is entered into the paint matrix. Over time, the toxin will leach out of the coating and will effectively kill off the surrounding biofouling. There are several issues with leachates. If a toxin is too quick to leave the coating matrix, the coating will fail prematurely. On the other hand, if the toxin is unable to leave the matrix in a timely manner, then the coating will lack the desired anti-fouling properties. In addition there are environmental regulations surrounding the toxins within the coating system. Make sure that you are using a coating that is in compliance with your local regulations.

An **ablative coating system** is designed to come apart (ablate) effectively removing the fouling as it ablates. These types of coatings are often referred to as self-polishing coatings. These ablative coatings are good for high-speed and commercial vessels and will generally leave the coating surface smooth. Ablative coatings may also be designed with leaching properties described above.

Foul-release coatings are typically flexible coatings with a smooth finish, which makes the surface hard for fouling to accumulate. The fouling which does accumulate on the surface is most often removed when the vessel reaches a designated speed. The mechanical motion of the vessel though the water provides enough friction to remove the accumulated fouling. Foul release coatings are often formulated from a silicone or fluoropolymer resin.

8.3.4 Chemical Resistance

The chemical resistance of a coating is a function of the interaction of the resin with a particular chemical. There are typically two resin types which need to be taken into consideration:

- **Convertible**. Resin cures into a polymeric film through a chemical reaction in which cross-linking is prevalent
- **Non-Convertible.** Resin is immersed in a solvent solution and will form a film when the solvent evaporates

Typically, thermoset materials will have greater chemical resistance since the thermoset reaction is irreversible and because thermoset materials have a high degree of cross-linking. In general, materials with a high amount of cross-linked polymer groups will have a greater chemical resistance. In other respects a high amount of cross-linking is not always a desirable quality. A chemical resistance chart is usually available, and it is supplied by manufacturer in the product catalog.

8.3.5 Color

The color of a coating is a function of the pigment within the coating. Prime pigments are responsible for imparting color and opacity to a coating. Any specific color is the combination of the particular pigments which when mixed together will create the illusion of that color. By manipulating the amount of each type of pigment added to the coating we are able to engineer endless colors.

Prime pigments can be further broken down into organic and inorganic pigments. Organic pigments typically have a greater brightness, intensity, and tend to tint better than inorganic pigments. Inorganic pigments, on the other hand, generally have greater resistance to chemical attack, heat, solvents and environments of extreme pH making them better candidates for high performance materials. As far as pricing, organic pigments typically cost more than inorganic pigments. Some colors have readily available organic and inorganic pigments, other colors may be driven in one direction. Black is such a color where the pigments are all inorganic.

8.3.6 Corrosion Control

There are three basic mechanisms of how a coating provides corrosion control:

- Barrier
- Inhibitive
- Sacrificial

Each of these methods differs in how the coating will protect the substrate. Simply put a barrier coating will protect the substrate by acting as a boundary between it and the surrounding environment. An inhibitive coating will also act as a barrier, but will chemically react with the environment to mitigate corrosion. Finally, a sacrificial coating will act as an anode and will corrode preferentially to the steel. All of these methods will act to protect the substrate, but once again, it is necessary to know about the specific application before deciding on which coating to use, as certain applications will not allow for the use of a particular mechanism.

8.3.7 Fire Inhibition

Fire inhibition is a coating's ability to curb the spread of fire. This is done through a few different means. One, which is used simply as a fire retardant, is to add additional components which are known to aid against the spread of fire. These additives include chlorines, halogens, phosphoric compounds and paraffins, though this list is not exhaustive.

Coatings can be specifically formulated to react to fire. One method is for the coating to self destruct to help put out the fire. Some of the coatings in this category are Intumescent coatings.

Intumescent coatings are used specifically to protect the substrate in the event of a fire. When a flame is applied to the surface of an intumescent coating, the coating will modify itself to form a rigid foam layer which will protect the substrate and help quench the fire. One of the other benefits of the intumescent coating reaction (when it turns to a foam) is that it off-puts gasses, which also help to put out the fire by eliminating access to oxygen necessary to sustain the fire.

8.3.8 Flexibility

As far as engineered properties go, flexibility is the opposite of hardness and abrasion resistance, which are associated with brittleness. Flexibility is the coatings ability to gradually adjust to mechanical deformation. Flexibility within a coating is often a desirable property if there is any type of motion or vibration associated with the substrate. Coatings which tend to be more flexible are:

- Themoplastic coatings or those which contain plasticizers
- Cross-linked polymers with large spaces between the cross-links
- Coatings with lower glass transition temperatures

8.3.9 Gloss

Gloss is often a desired property for aesthetic reasons. There are several different generic designations of gloss in coating applications:

- Flat - 1-9% Gloss
- Eggshell – 26-40% Gloss
- Semi-gloss – 41-69% Gloss
- Full-gloss – 70-89% Gloss

Gloss is an engineered property which is a function of pigment. In the case of gloss, the smoother surfaces tend to be more reflective and hence are considered to be more glossy. Gloss also improves with lower pigmentation concentration. Additionally, increasing the pigmentation concentration will increase the hide properties of the coating.

8.3.10 Hardness

Hardness typically refers to the coating's ability to withstand deformation or damage from external forces. In general, the overall hardness of a coating is determined by the chemistry of the coating. Chemical properties which affect the hardness of a coating include:

- **Prevalence of cross-linking within the polymer**
  - Greater amount of cross-linking yields a harder surface
- **Glass transition (Tg) temperature**
  - As the Tg of the coating decreases so does the hardness of the coating
- **Pigment choice**
  - Choosing pigments which are generally hard will increase the overall hardness of the coating

8.3.11 Rapid Cure

Rapid cure is an engineered property in which the cure time of the coating is very short. It is useful in many applications where standard cure times are simply too long. The ability of a coating to rapidly cure is influenced by:

- the choice of the base resin and curing agent.
  - The interaction between the base resin and the curing agent will determine the rate of curing
- The reactivity/functionality of the molecules within the coating structure
- The viscosity of the coating

Rapid cure technologies are being explored heavily for several industries and applications. One such industry is the shipping industry where turnaround time is key.

8.3.12 Temperature Resistance

Temperature resistance is the coatings ability to withstand drastic temperatures and changes. The ability to withstand drastic temperature changes lies within the selected resin system.

- Different resin systems will have different decomposition points depending on the material.
- Thermoset resins will tend to withstand greater temperatures than thermoplastic resins. As heat can act in the same manner as a solvent and melt a thermoplastic material.
- Inorganic resins are typically more tolerant of high temperatures.

8.4 Additional Considerations for Coatings Selection

In addition to thinking about desired coating properties, it is necessary to take into account outside influences which can affect the coating system. One system which is well known within the corrosion world to have a detrimental effect on a coating system if not properly taken into consideration is cathodic protection. Cathodic protection systems are used to help protect the structure from unwanted corrosion damage. Some known impacts of incompatible cathodic protection systems on coatings are:

- Blistering
- Disbondment
- Chemical attack of the coating due to high alkalinity near the substrate

All of these impacts are detrimental to the coating and are known causes of premature coating failure. In order to prevent these issues from occurring it is best to test the coating system for its cathodic disbondment properties. Cathodic disbondment testing is exposure specific. An example is ASTM G8 which is the standard for cathodic disbondment testing of pipeline coatings.

Overvoltage of the cathodic protection system is a cause of the detrimental effects listed above. Make sure that your coating system can handle the voltage requirements of the cathodic protection system. In areas where it is known that there will be a high voltage, use a dielectric shield.

8.4.1 Concrete Considerations

Concrete acts very differently than steel so it is important to understand specific issues with coating selections for concrete:

- Thoroughly inspect concrete surface
- Determine compatibility with existing coatings
- Prioritize desirable coating properties
- Evaluate the service exposure
- Consider possibility of contaminating any contained products
- Consider normal and upset condition
- Evaluate amount of time available to do work, allowing sufficient time for proper cure

8.5 Summary

Once you have weighed your options and selected your desired coating system for your particular service, ensure that coating system is properly identified in the specification. Be specific in specifying the system needs. Do not be vague and use terms such as “or equal.”

Chapter 1: Coating and Lining Issues in Various Industries

OBJECTIVES

Upon completion of this chapter, you will be able to:

OBJ 1.1: Recognize issues that affect the use of coatings in various industries.

1.1 External Factors Influencing Coating and Lining Use

It is important for you to understand the various technologies used in the coatings and linings industry. These technologies include numerous chemistries, surface preparation equipment, application equipment, and inspection/testing equipment as well as special techniques for each.

The coating works as *part of a larger engineering system* — whether a bridge, pipeline, storage tank, or process vessel. Understanding the coating-related technologies is only part of the knowledge a coatings expert must have. You also have to understand that ***industry-specific external factors*** influence each industry's use of coatings and linings.

The external factors that influence the use of coatings and linings can be broadly grouped into four classifications:

- Operational issues
- Operating conditions
- Legacy materials and practice
- Management philosophy

1.1.1 Operational Issues

Operational issues occur in areas where the coating will be used and generally have the greatest impact during coating installation. They include:

- **Impact of equipment downtime** – coatings with faster cure, fewer coats, and requiring less surface preparation may be a better choice
- **Interference between coating operations and facility operation** – surface preparation methods with low dust generation may be required
- **Life expectancy of the asset being coated** *(or the coating itself)* –applying a 20-year coating system to an asset which must be rebuilt every 5 years may not make sense
- **Inspection requirements** – many items require coating removal to be properly inspected
- **Risk tolerance** – some coatings have a higher consequence of failure and therefore application must meet higher levels of quality

1.1.2 Operating Conditions

The operating conditions of a particular structure should always be a major factor in coating selection. This includes all of the elements to which the coating will be subjected.

- The ambient exposure environment in which the coating functions may be an outdoor environment or a product to be contained within a lined tank in any of these areas:
    - Marine
    - Industrial
    - Rural
    - Interior

- The **specific service exposure** can be more complicated. For example, if a structure is operating at high temperatures and exposed to acid fumes, the coating must withstand both conditions to be effective. Bridge coatings used near expansion joints must withstand frequent wetting with contaminated water runoff. Coatings used in potable water tanks must withstand water immersion while not contaminating the water. General examples of specific service exposures include:
  - Chemical splash and spill
  - Immersion
  - Operating temperature
  - Mechanical stresses

- Upset conditions refer to conditions outside normal operating expectations that are likely enough to occur to be taken into consideration. For example, a vat properly coated on its interior for its contents, might have an exterior coating that is only mildly resistant to the contents. If the vat overflowed, the exterior coating would fail. In this case, a highly resistant coating for both the interior and exterior of the vat might be a better choice. Another upset condition is the coating's ability to withstand mechanical damage (e.g., impact, abrasion, or wear). Most coatings should be designed to withstand corrosion, undercutting, and delamination when mechanical damage exposes the steel substrate.

1.1.3 Legacy Materials and Practices

Often things are done a certain way because *"we've always done it that way."* You must understand and consider the legacy materials and practices used in various industries when designing a coating project.

Legacy materials can impact coating operations in many ways. Some owners will completely remove lead-based paints regardless of their condition to mitigate the health risk, especially where there is possible public contact with the lead paint.

Legacy materials can also impact decisions about new construction. It is simpler to manage a facility when the various coating systems are compatible and known. Most facilities have a set of general specifications for coatings in their facility. This minimizes or eliminates the need to test coatings for compatibility and/or performance during routine maintenance, i.e., if a coating works in a particular service environment there is no need to test other coatings, but if conditions change using the legacy coating could be the wrong choice and the coating selection would need to be re-assessed.

Legacy practices can also drive coatings selection. For example, the U.S. Navy continues to use a gray alkyd coating on most of a ship's topside coated surfaces despite the availability of more durable technologies. While there are a number of reasons for this, one of the key reasons is that sailors can easily apply the alkyd coating at sea so the ship will look good as it comes into port. More advanced two-component spray applied coatings would be difficult for a relatively untrained sailor to apply at sea.

1.1.4 Management Philosophy

Different owners, designers, and managers have different philosophies for coating practices and how they are weighed with industry standards. Each philosophy has some analytical rationale. Common management philosophies include:

- Appearance vs. Function

- Life Cycle Costs vs. Initial Cost
- Construction Materials vs. Coatings

Sometimes the areas most visible to the public will be maintained based on appearance while less visible areas will be allowed to show minor corrosion. Alternatively, in the entertainment industry, gloss and color will be the focus – any level of corrosion may be unacceptable.

1.2 Case Study 1

The instructor will assign each table an industry to examine. The list of industries includes:

- Chemical and refining
- Pulp and paper
- Mining
- Power
- Food and beverage
- Sewage treatment and transport
- Water storage and transport
- Rail car lining
- Waterway and port
- Shipping
- Motor Vehicle
- Highway bridge
- Liquid gas and pipeline
- Offshore

Complete the written assessment on the following page and the worksheet for your assigned industry. Each group will have 10 minutes to complete the assignment and 5 minutes for a single presenter to report the group's findings to the class.

1. Identify the industry and, if appropriate, any subcomponent of the industry (for example: "tank painting in refineries," "highway bridges," or "wastewater treatment").
2. Develop a bulleted list of important elements in each of the categories identified on the worksheet.
3. In one or two paragraphs, summarize the key issues that an outsider should recognize about the industry. This is the summary your group member will report to the class.

Chapter 1 Case Study Worksheet

1. Operational Issues:
2. Environment/Exposure:
3. Legacy Materials and Practices:
4. Management Philosophy:

Summary of Key Issues in the Industry (present to class)

Chapter 10: Surveys and Maintenance

OBJECTIVES

This chapter details the normal assessment procedures used to determine the condition of a structure or facility before beginning a protective coatings project.

Upon completion of this chapter you will be able to:

- Divide the facility or structure into meaningful parts.
- Select an appropriate test to determine the condition of the substrate. Determine Condition of Substrate
- Select an appropriate test to determine the condition of the existing protective coating system
- Identify the environment in which the protective coating systems must function
- Estimate the surface area to be coated

10.1 Coating Surveys

Before applying new coating systems or coating to maintain existing coating systems, precise data on existing conditions are needed to know how they will affect the coating project.

A properly conducted condition survey provides that information because it includes intentional fact gathering on how well the structure or facility is resisting corrosion. A simple walk-through to see how the structure looks does not provide this detailed information.

Surveys are conducted to reveal several conditions about the coating:

- First indications of coating failure
- Critical areas of concern
- Areas that require further evaluation
- Evidence of a well-managed corrosion control program
- Long-term asset management

10.2 Planning a Survey of a Facility or Structure

Surveys (inspections) can performed at different levels. Less expensive and simpler inspections are used more frequently while more costly inspections are performed according to specific needs. Before you can start, basic decisions need to be made about that will affect how the survey will be accomplished.

10.2.1 Breaking the structure into manageable number of parts

A good survey divides the structure or facility into easily defined parts and then methodically notes exactly what has happened to the structures and the coating systems since it was last coated.

10.2.2 Establishing standard evaluation criteria

The evaluation criteria for the survey typically follows a two-tiered approach; either of the following methods is valid.

- By structure selection: Conduct visual observations on all structures and perform detailed tests on selected structures

OR

- By frequency: Conduct visual observations annually and perform the detailed tests less frequently.

10.2.3 Determining the level of inspection needed

There are three survey levels – basic, intermediate and advanced - each requiring different techniques:

- Basic Survey - Primarily visual in nature, with photographic and written documentation
- Intermediate Survey - Determines extent and severity (e.g., depth of penetration, loss of section) of corrosion. Uses basic tools such as ultrasonic testing.
- Advanced Survey (if necessary) - Uses more sophisticated inspection techniques (e.g., radiography); usually involves specialized consultants.

10.2.4 Determining if the inspection is an initial survey or a follow-up survey

Initial surveys take longer to perform because they include figuring out how to break down the structure. They also need to capture the descriptive and historical data (surface area, last coat date, existing coatings, etc.)

Follow-up surveys are more efficient to do because they only require determining the condition of the coating and recording any coating work that was performed since the last survey.

10.2.5 Deciding what data to collect

10.2.5.1 Useful data

The data collected during a survey should be gathered efficiently, reproducibly, and accurately. That means using standard testing methods, such as ASTM procedures. Inspectors should also compare notes to be sure they are rating their findings comparably, whether they are using a simple rating scale (1 to 5) or using ASTM procedures.

10.2.5.2 What data is needed?

The planning for the survey should take into account precisely what the issue is: Is the concern about aesthetics, a chronic or acute corrosion problem? While both % breakdown and corrosion pitting may both be concerns, data related to different coating management goals need to be tracked separately, for example, corrosion and coating loss would be considered two separate problems. The overall goal is to collect only what data is needed. Collecting non-useful data is a waste of time and money.

10.2.5.3 How much data to collect

In planning the survey and data collection, always consider the necessity of each type of data to be collected in view of these questions:

1. What information is actually needed
2. What information can be acted upon
3. What is important/what matters to the facility's management
4. What is affordable

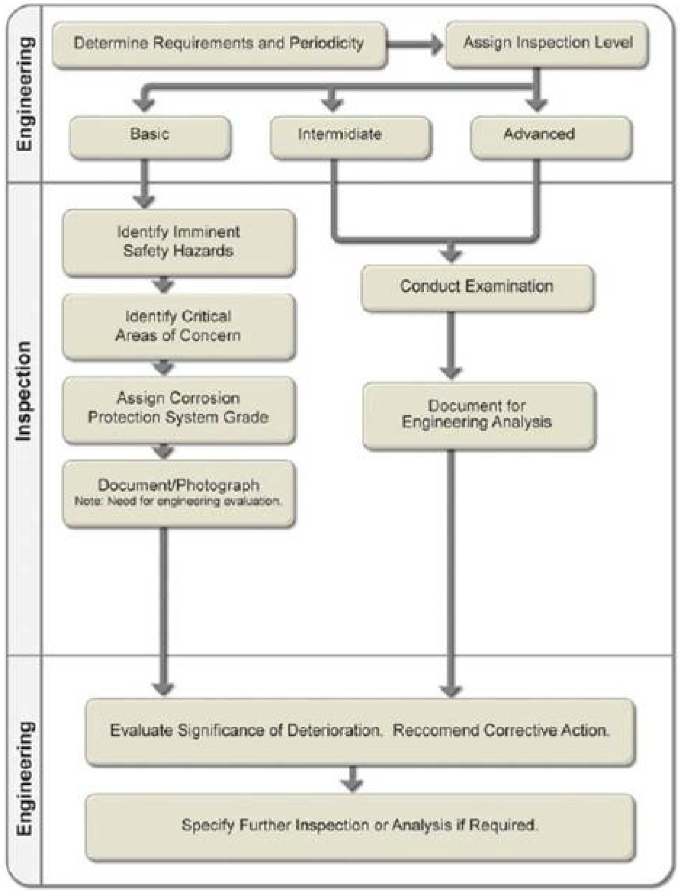


Figure 10.1 Sample Coating Maintenance Program

10.3 Main Steps in a Coating Survey – Overview

Conducting a coating survey requires performing six key steps. Each of these steps will be described in more detail in the sections that follow.

Step 1. Divide the facility into meaningful subcomponents

Step 2. Evaluate the substrate condition

Step 3. Evaluate the coating condition

Step 4. Estimate the square footage of coated surface

Step 5. Maintain a set of consistent records

Step 6. Utilize the data for planning the coating's maintenance

10.4 Divide the Facility into Meaningful Parts

As mentioned in the Planning a Survey section, the first step is to break the facility or structure down into manageable parts. In order to ensure that every part of the facility or structure is surveyed, it must be divided into meaningful parts that are **named and numbered consistently**.

This should be done before the survey begins. However, some adjustments may be required during the survey.

10.4.1 Facility breakdown approaches

For accurate planning purposes and to make conducting the condition survey as simple as possible, **minimize the number of component groupings.** This can be done using one or a combination of approaches:

- Divide the facility in logical groups that could be coated at the same time, with the same procedures (same kind of work, same surface preparation, or application requirements). This means the work can be done in order and can steadily progress.
- Divide the facility based on operating environments (immersed, interior, exterior, etc.)
- Adopt an existing breakdown of the facility (tank numbers, operation zones, etc.)
- Create breakdown groups or zones that cover as large an area as possible. This means fewer evaluations and a simpler survey process.

10.4.2 Facility breakdown details

- To keep track of the survey data collected, each element in the breakdown must be identified., first develop a consistent element identification scheme. Then collect the basic data on each identified element.
- Size (square footage to be coated)
- Location
- Substrate types
- Coating systems
- Color
- Operating environment
- Group common areas together; this makes the task easier to manage.

10.4.3 Tips for Estimating Surface Area to be Coated

When estimating surface area for the basic data collection part of the survey, look at the task from a coating applicator's perspective, not an engineering perspective. Follow these tips:

- Round up to nearest foot
- Minimum surface area for items like pipes is 1 sq foot per linear foot
- Remember to account for the increased length of curved items
- Measure fabricated items (chain link fence, open joists, gratings) as solid objects
- Disregard openings in continuous surfaces of <100 sq ft
- Do not deduct surface areas associated with items that restrict access like machinery

10.5 Develop standardized evaluation criteria for condition of substrate and coating

In order to have the survey results be useful to the facility's managers, those conducting the survey first need to know the purpose of the coating. Is it for aesthetics? For corrosion control?

A matrix grading system (see Table 1.1) to evaluate the extent of both coating degradation and substrate corrosion allows you to systematically and consistently assess the condition of facility's elements. Although a grading system can be challenging to apply consistently and objectively, it can simply the analysis of observations made during the survey.

Other grading systems may be developed in unique cases where other issues (color/gloss or surface roughness) are deemed to be critical grading factors.

Table 10.1: Matrix of Coating Degradation and Substrate Corrosion

		Coating Degradation				
		0–10%	**6–10%**	**11–25%**	**26–50%**	**50–100%**
Degree of Substrate Corrosion	None to light rust staining	**1**	**1**	**1**	**2**	**2**
	General light rust, passive	**1**	**2**	**2**	**3**	**3**
	Heavy rust, active	**2**	**3**	**3**	**4**	**5**
	Deep pitting	**3**	**4**	**4**	**5**	**5**
	Significant metal loss	**4**	**4**	**5**	**5**	**5**

10.6 Visual Rating Methods for Assessing Coating Conditions

Various industry standards address protective coatings degradation and associated rusting. These standards typically address the coatings system and not the actual substrate condition. They specify how to assess the degree of corrosion, degree of blistering, other defects such as flaking and chalking, and how to describe the extent and distribution of the affected area.

10.6.1 ISO Standards

The International Organization for Standardization (ISO) test methods include these relevant to evaluating coatings:

Table 10.2: ISO 4628 Paints and varnishes – Evaluation of degradation of paint coatings – Designation of intensity, quantity and size of common types of defect	
Part 1	General principles and rating schemes
Part 2	Designation of degree of blistering
Part 3	Designation of degree of rusting
Part 4	Designation of degree of cracking
Part 5	Designation of degree of flaking
Part 6	Rating of degree of chalking by tape method

10.6.2 ASTM Standards

Test methods and standards relevant to coatings condition assessment published by ASTM International are:

- ASTM D610, Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces
- ASTM D5043, Field Identification of Coatings
- ASTM D3359, Measuring Adhesion by Tape Test
- ASTM D4541, Pull-Off Strength of Coatings Using Portable Adhesion Testers
- ASTM D1186, Test Methods for Non Destructive Measurement of Dry Film Thickness of Non-Magnetic Coating Applied to a Ferrous Substrate
- ASTM D1400, Test Methods for Non Destructive Measurement of Dry Film Thickness of Non-Conductive Coating Applied to a Non-Ferrous Substrate
- ASTM D4138, Standard Test Methods for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means
- ASTM D4214, Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films
- ASTM D714, Standard Test Method for Evaluating Degree of Blistering of Paints
- ASTM D968, Standard Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
- ASTM D772, Standard Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints

10.6.3 SSPC Standards

Guide to Visual Standard No. 2 – Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces.

A rust grade is assigned to the facility or element of the facility by the percentage of rust and the distribution of that rust on the surface.

The rust distribution is defined as:

- **Spot rusting** — localized corrosion of the facility element.
- **General Rusting** — a random distribution of corrosion over the surface.
- **Pinpoint Rusting** — small spots of corrosion on the surface.

The actual condition of corrosion typically encompasses several of these rust conditions. A general description of the rust grades described in SSPC-VIS 2 is presented in Description on SSPC-VIS 2 Rust Grades.

Table 10.3: Description on SSPC-VIS 2 Rust Grades

SSPC Rust Grade	% of Surface Rusted	Photographic Standard		
		Spot	**General**	**Pinpoint**
10	≤0.01%	None	None	None
9	>0.01% to 0.03%	9-S	9-G	9-P
8	>0.03% to 0.1%	8-S	8-G	8-P
7	>0.1% to 0.3%	7-S	7-G	7-P
6	>0.3% to 1.0%	6-S	6-G	6-P
5	>1.0% to 3.0%	5-S	5-G	5-P
4	>3.0% to 10.0%	4-S	4-G	4-P
3	>10.0% to 16.0%	3-S	3-G	3-P
2	>16.0% to 33.0%	2-S	2-G	2-P
1	>33.0% to 50.0%	1-S	1-G	1-P
0	>50.0%	None	None	None

10.7 Determine Condition of Substrate

Determining the condition of the substrate is a critical part of any condition survey. Coatings can mask some rather severe corrosion for a limited period of time. Insulation is particularly guilty of hiding corrosion. Contaminants from process or environmental upsets cannot generally be seen unless the underlying substrate is revealed.

10.7.1 Visible Rust

If there is visible rust, the extent of rust and depth of pitting must be established. This can be estimated in accordance with ASTM D610, Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces.

The standard calls for rating the extent of rusting on a 0 to 10 scale as shown in the Guide to ASTM D 610. The standard also requires the inspector to qualify the rusting as:

- **S = Spot:** Occurs when bulk of rusting is concentrated in a few localized areas of painted surface.
- **G = General:** Occurs when various size rust spots are randomly distributed across surface.
- **P = Pinpoint:** Occurs when rust is distributed across surface as very small individual specks of rust.

- **H = Hybrid:** Actual rusting surface may be a hybrid of types of rust distribution depicted in the visual examples.

Thus, a rating would consist of a letter and number (e.g., 7-H, 3-S, 9-G). ASTM provides a graphical representation of the rust descriptions for reference.

Table 10.4: Guide to ASTM D 610

Rust Grade	% of Surface Rusted
10	Less than or equal to 0.01%
9	Greater than 0.01% and up to 0.03%
8	Greater than 0.03% and up to 0.1%
7	Greater than 0.1% and up to 0.3%
6	Greater than 0.3% and up to 1.0%
5	Greater than 1.0% and up to 3.0%
4	Greater than 3.0% and up to 10.0%
3	Greater than 10.0% and up to 16.0%
2	Greater than 16.0% and up to 33.0%
1	Greater than 33.0% and up to 50.0%
0	Greater than 50%

10.7.2 Blisters

The size of blisters can be described using the ASTM D 714 “Standard Test Method for Evaluating Degree of Blistering of Paint.” The standard uses a numerical scale ranging from 10 to 0 in which 10 represents no blisters.

Density is described with four levels:

- Dense, D
- Medium Dense, MD
- Medium, M
- Few, F

Reference photographs showing both blister size and density are included in the standard. Although the standard does not describe the shape, the inspector should draw a diagram of any blister that is not oval and should also identify the location of the blisters on the structure.

10.8 Tools and Instruments

The inspection process is primarily visual in nature, but coating inspectors also conduct specialized tests.

Non-Destructive Tests

- Dry film thickness (DFT)
- Lead check
- Color
- Gloss
- Remaining substrate thickness
    - Ultrasonic
    - Radiographic

Destructive Tests

- Destructive DFT measurements
- Cross hatch adhesion
- Pull-off adhesion
- Removal of paint sample
- Laboratory evaluation of chemistry
- Determine heavy metals content

10.8.1 Dry Film Thickness (DFT) Measurement (Non-Destructive)

To determine needed maintenance the thickness of the existing coating system must be determined. DFT gauges are used to make that determination.

SSPC-PA 2, "Measurement of Dry Paint Thickness with Magnetic Gauges," describes the use of the two basic types of magnetic gauges:

- Type I Magnetic Pull-Off Gauges
- Type II Fixed-Probe Electromagnetic Gauge

Both Type I and II gauges are used to determine the DFT of non-magnetic coatings over a magnetic (usually ferrous) substrate.

Frequently, **nonmagnetic and/or nonconductive coatings** are applied over conductive nonferrous substrates such as aluminum, zinc, copper, brass, and some stainless steels.

Test instruments using the Eddy current principle are used to determine the DFT of nonconductive coatings over these surfaces.

The following two ASTM Standards address the use of magnetic DFT gauges and Eddy current type gauges:

- ASTM D1186, "Test Methods for Nondestructive Measurement of Dry Film Thickness of Non-Magnetic Coatings Applied to a Ferrous Substrate"
- ASTM D1400, "Test Methods for Nondestructive Measurement of Dry Film Thickness of Non-Conductive Coatings Applied to a Non-Ferrous Substrate"

10.8.1.1 Type-I Magnetic Pull-Off Gauges

These gauges use a spring to lift a small permanent magnet from the surface of the coating. Because the force holding the magnet to the surface varies with the distance between the magnet and the steel surface, i.e., the thickness of the coating, the gauge can translate the force needed to lift the magnet off the surface into a measurement of the coating's thickness.

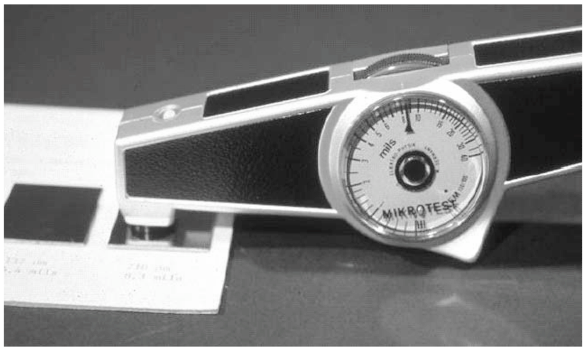


Figure 10.2 Dial-Type Magnetic Pull-Off DFT Gauge

10.8.1.2 Type-II Electromagnetic DFT Gauges

These gauges use direct current to induce a magnetic field, which then interacts with the ferrous metal of the substrate in exactly the same manner as the permanent magnet of the pull-off gauge.

The fixed probe of the Type-II gauge must remain in contact with the coating film during measurement. When the digital read out stabilizes, it can be read off the digital indicator.

Figure 10.3 Magnetic Constant Pressure DFT

10.8.1.3 Factors Affecting Electromagnetic DFT Gauges

Factors that affect the accuracy of electromagnetic gauges include:

- **Magnetic properties of the substrate.** For best accuracy, the calibration piece should be the same metallurgical composition as the coated item being measured.
- Different steel alloys, and measurement of coating thickness on castings can change the gauge accuracy, requiring recalibration.
- **Substrate thickness.** Required minimum substrate thickness will vary from instrument to instrument. Some instruments require more "magnetic bulk" or mass than others to maintain consistent accuracy.

- **Edges.** Generally accurate measurements cannot be made closer than 1 in. (25 mm) to any edge.
- **Curved surfaces.** The probe should be held at a right angle to the surface used to measure DFT; calibration should be done on a similar curved surface (if possible).
- **Magnetic coatings.** Measuring DFT of partially magnetic coatings (containing micaceaous iron oxide pigment) can pose problems; follow the manufacturer's recommendations.
- **Configuration of substrate.** If the substrate is smooth or roughened by blast-cleaning can affect measurement accuracy. Calibrate on a substrate similar to that being coated, unless otherwise specified.

The specific instructions and recommendations of the instrument manufacturer should be carefully studied and complied with.

10.8.1.4 Eddy Current DFT Gauges

These measure the DFT of **nonconductive films** applied to **conductive substrates**, most often non-ferrous metals such as:

- Aluminum
- Copper
- Brass
- Stainless steel

The instrument may look exactly like electromagnetic gauges, but it induces an eddy current in the substrate by alternating current fed to the probe.

Measurements can be made on any conductive metal; the shape and size of the probe and the conductivity of the metal substrate are significant.

Instruments that can operate under both electromagnetic *and* eddy current principles usually use a separate probe for each principle. Some eddy current gauges use separate probes for ferrous and nonferrous substrates.

Factors affecting the accuracy of eddy current gauge measurements

- **Magnetic and conductive properties of the substrate.** For highest accuracy, calibrate on a substrate with the same metallurgical composition as the coated item being measured.
- **Substrate thickness.** Depending on the specific instrument, required minimum substrate thickness will vary. Some instruments will work over substrates as thin as a few mils.
- **Edges.** Measurements made closer than 1 in. (25 mm) to any edge may not be accurate.
- **Curved surfaces.** Hold probe at right angles to the surface. Calibrate (if possible) on a similar curved surface.
- **Conductivity of coatings.** Measuring DFT on aluminum pigmented coatings almost always poses problems; follow manufacturer's recommendations.

The specific instructions and recommendations of the instrument manufacturer should be carefully studied and complied with.

10.8.1.5 Eddy Current DFT Gauge Calibration

Plastic shims of known thickness are used to calibrate the gauge. The shim thickness should be in the thickness range of the coating to be measured. The plastic shims should be placed over a substrate of sufficient mass for the instrument to be used.

Once calibration is done, measurements should be reasonably accurate across the scale; that is, at intermediate points between the calibration values used.

10.8.2 Dry Film Measurements (Destructive Means)

10.8.2.1 The Tooke Gauge

These destructive methods of measuring dry film thickness use a paint inspection gauge to measure the thickness of individual layers of coatings in a multicoat film in addition to measuring the total thickness. For the measurement, the coating film is cut at an angle, revealing the number of coats present that can then be measured. The instrument is often referred to as a Tooke gauge after its inventor, H. Tooke. Its use is governed by ASTM D4138, "Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means (Method A)."

Several styles of Tooke gauges are used.

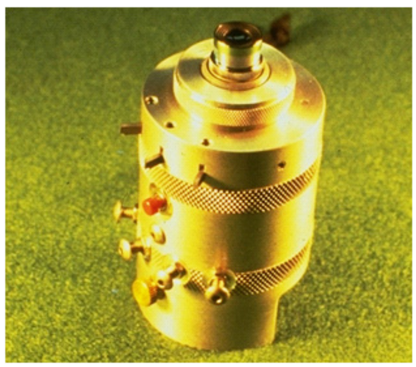


Figure 10.4 Cylindrial Tooke Gauge Model

10.8.2.2 Tooke Gauge Operation

The Tooke gauge is fitted on one side with factory-set guide studs in precise alignment with a cutting tip. One side of the gauge is equipped with an illuminated 50X microscope. The eyepiece of the scope contains a measuring reticle, which establishes scale.

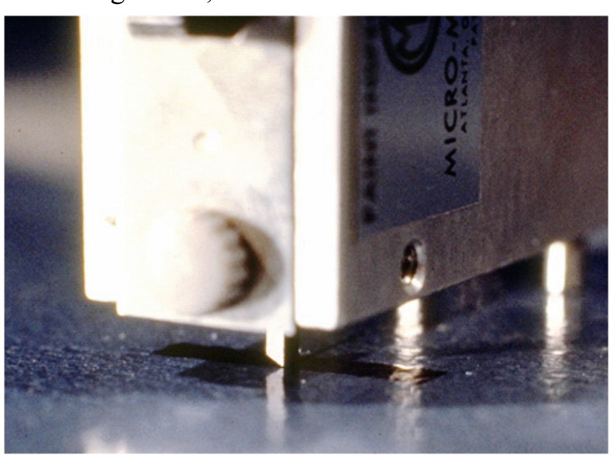


Figure 10.5 Guide Studs

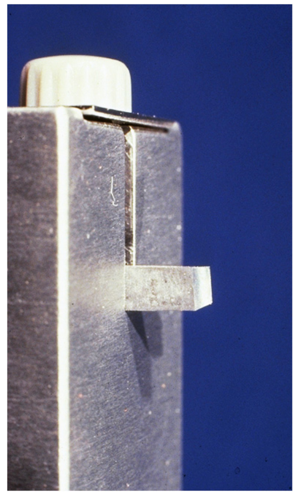


Figure 10.6 Cutting Tip

10.8.2.3 Uses of Tooke Gauges

Tooke gauges are **destructive** test instruments used to:

- Measure total DFT of coatings up to 1,270 µm (50 mils).
- Measure DFT of each coat of paint of contrasting colors. It may be difficult to distinguish between multiple coats of material of the same color.
- Assess abrasive blast cleaning work. It also can detect mill scale not removed by blasting.
- Measure DFT of coatings on concrete, ceramics, plastics, etc.

10.8.2.4 Advantages of Tooke Gauges

The Tooke gauge offers specific advantages, such as:

- Portability
- Useful in the field or in the lab
- Relatively easy to use
- Can mount camera and take pictures through the microscope
- Reliable referee instrument in case of arbitration

10.8.2.5 Disadvantages of Tooke Gauges

The Tooke gauge has certain disadvantages:

- Needs battery power
- Must destroy section(s) of coating to conduct test
- May not produce smooth cut in filled or fiber coatings
- Soft or elastic coatings may need to be cooled or frozen with dry ice to allow a good cut
- May not be intrinsically safe

10.8.3 Adhesion Tests

Most coatings properly applied to a well-prepared surface have good adhesion to the substrate. However, some users may choose to conduct spot adhesion tests to determine the quality of the coating's bond to the substrate, as well as between the coats. Adhesion tests check the ability of the coating to resist removal from the substrate. These may also be used to investigate coating failures.

Some of standards used for adhesion tests are:

- ASTM D6677, Knife adhesion
- ASTM D3359, Tape adhesion
- ISO 2409, Cross-cut test
- ASTM D4541, Pull-off strength test using a fixed-alignment adhesion tester Type 2

10.8.3.1 Knife and Micrometer Testing

A pocket knife or a very sharp putty knife or scraper can be used for a quick adhesion test. Use the knife to cut through the coating, and try to peel the coating from the substrate.

This is a **highly empirical test**, and the evaluation of bond strength is merely the opinion of the evaluator and the results may be subject to dispute. However, if the coating is easily peeled from the surface, then the adhesive bond to the substrate is unacceptable.

If the coating can be dislodged from the surface in tiny pieces by picking with the knife, then the bond may be totally acceptable. If this test is used, the parties involved need to agree about how to evaluate the test results.

The thickness of the coating sample (paint chip) that's been removed can then be measured using a micrometer. **Tape Pull-Off Test**

ASTM D3359, "Standard Test Method for Measuring Adhesion by Tape Test," describes two methods for measuring adhesion:

In **Method A** an X cut is made in the coating film (Figure 10.7). This method is used for coating films thicker than 5 mils (127 µm).

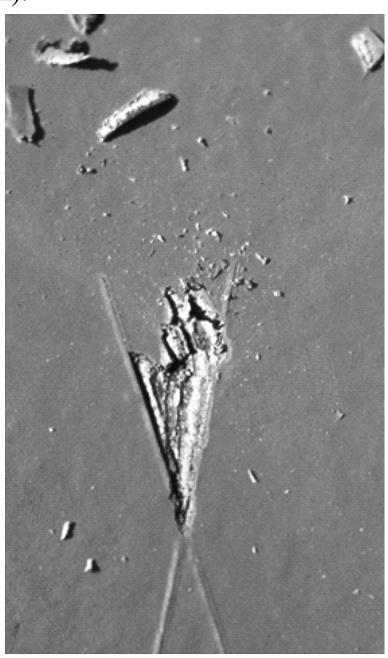


Figure 10.7 Method A: X-cut after Tape Removal

In **Method B** a series of cuts are made at right angles to each other (Figure 10.8 and Figure 10.9).

- For films thinner than 2 mils (50.8 µm), 11 cuts are made 1 mm (25.4 µm) apart in each direction.
- For coating films from 2 to 5 mils (50.8 to 127 µm), six cuts are made 2 mm apart at right angles to each other.

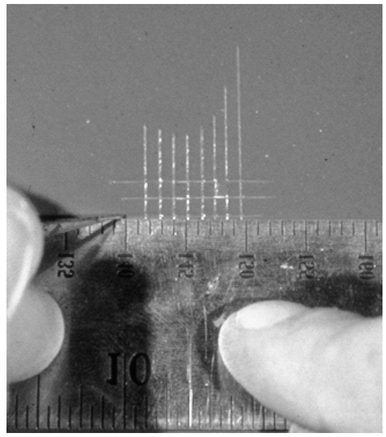


Figure 10.8 Method B: Making Cuts for Cross Hatch Tape Test

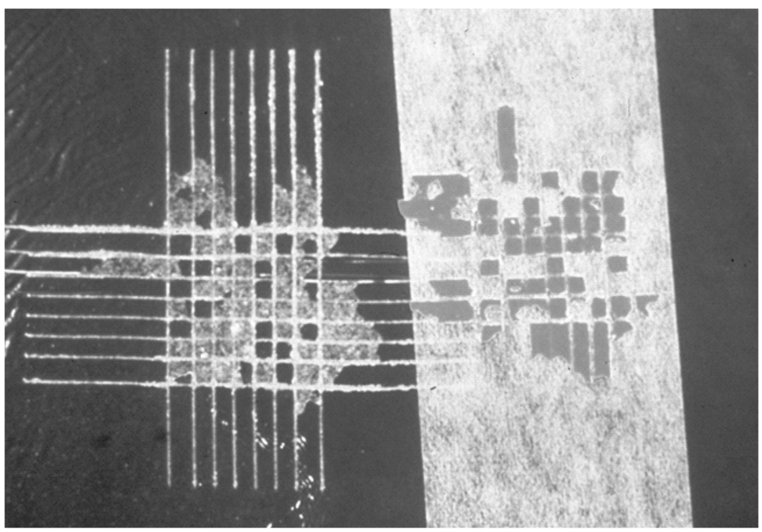


Figure 10.9 Tape After Cross Hatch Test

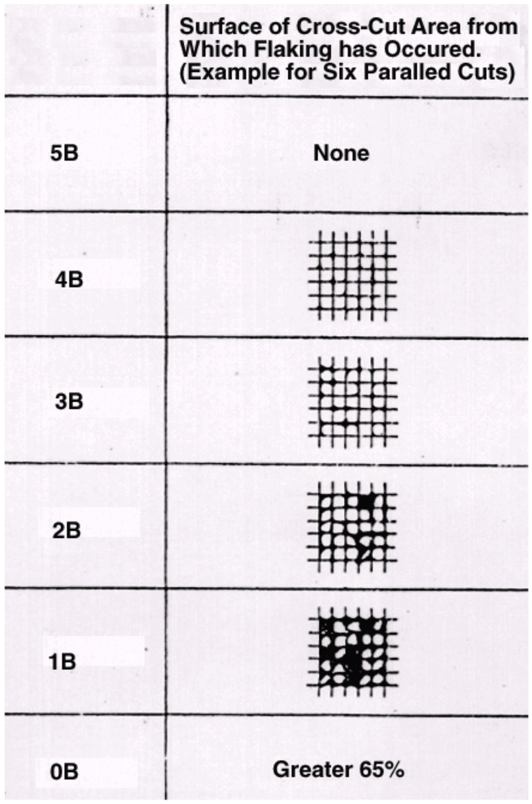


Figure 10.10 Classifications of Adhesion Tape Test Results

The ASTM descriptions (Figure 10.10) for rating the adhesion when this test is performed using Method B's cross-hatch cuts are:

5B: The edges of the cuts are completely smooth; none of the squares of the lattice is detached.

4B: Small flakes of the coating are detached at intersections; less than 5% of the area is affected.

3B: Small flakes of the coating are detached along the edges and at the intersections of the cuts. The area affected is 5 to 15% of the lattice.

2B: The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35% of the lattice.

3B: Small flakes of the coating are detached along the edges and at the intersections of the cuts. The area affected is 5 to 15% of the lattice.

2B: The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35% of the lattice.

1B: The coating has flaked along the edges of cuts in large ribbons, and whole squares have detached. The area affected is 35 to 65% of the lattice.

0B: Flaking and detachment worse than Grade 1.

A specially designed tool can be used to make the cuts needed for this test. The cross-hatch cutter consists of either a 6-blade or an 11-blade cutter in a holder (Cross Hatch Cutter with Six Blades

and Using Cutter Tool to Make Cuts). Make the cuts by pressing the teeth of the cutter to the test surface and pulling the cutter once in each direction to intersect at a 90-degree angle.

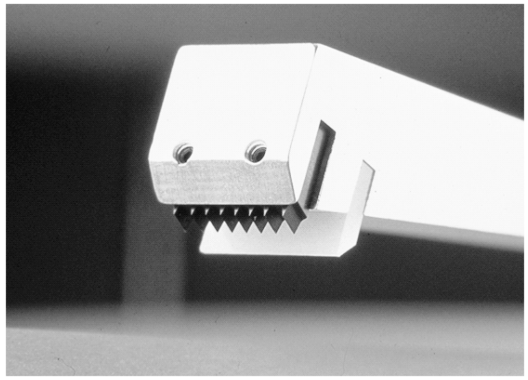


Figure 10.11 Cross Hatch Cutter with Six Blades

Note that some coatings with good pull-off test adhesion results do not give very good cross-hatch adhesion test results. Coatings that are brittle tend to fracture badly when tested by this method.

Cross-hatch cuts can also be made using a razor-sharp blade and an appropriate template guide with a 1-, 2-, or 3-mm separation.

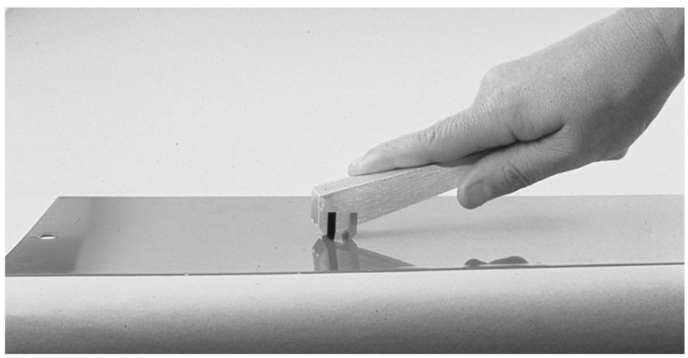


Figure 10.12 Using Cutter Tool to Make Cuts

10.8.3.2 Pull-Off Adhesion Tests Using Portable Testers

A more precise method of measuring coating adhesion, particularly in multicoat systems, may be required.

This method is described in ASTM D4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers, Annex A-2." (Figure 10.13.) It covers the procedure and apparatus to evaluate the adhesion of a coating by determining:

- Either the greatest perpendicular force (in tension) that a surface can bear before a plug of material is detached

OR

- If the surface remains intact at a prescribed force (pass/fail).

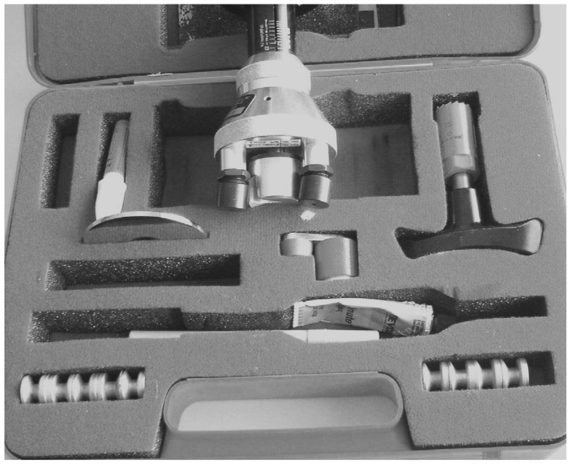


Figure 10.13 Portable Adhesion Tester Kit

This method minimizes tensile stress compared with the shear stress applied by other such methods as scratch or knife adhesion, and the results may not be comparable.

The portable adhesion tester used is capable of applying a concentric load and counter load to a single surface so coatings can be tested even though only one side is accessible.

Measurements are limited by the strength of the adhesion bonds between the loading fixture and the coating surface, or the cohesive strength of the substrate.

Figure 10.14 Turning Hand Wheel

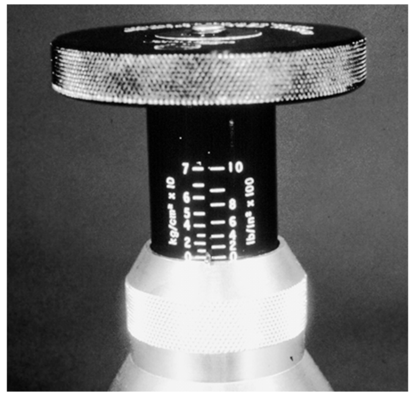


Figure 10.15 Close-up of Indicator

10.9 Estimating Square Footage for Budget Purposes

If the original drawings are available, the square footage of entire subsections of a structure can be calculated accurately, but such information is rarely available. Surface areas often need to be estimated during the survey. Estimates are needed to:

- Fill in initial databases
- Estimate smaller areas requiring:
  - Spot blasting
  - Spot priming
  - Spot topcoating
  - Full refresher topcoating

Although estimating guides are available from a variety of sources, the estimate will still depend on the experienced eye of the surveyor. Flat surface perimeter areas can be measured, and factors for amounts of structural stiffeners, beams, etc., can be used to calculate a meaningful amount of square footage for material ordering purposes.

10.10Documenting and Recording Systems

Use hard-copy or computer-based forms to document the results of the condition survey. The survey forms should include the survey date and the surveyor's identification.

The survey date helps measure the performance of the applied coating systems. Comparing condition grades as they change over time helps calculate the deterioration rate. Compare the deterioration rate with that predicted to get an indication of actual performance. Systems that deteriorate more rapidly than predicted should be subject to review and possible modification.

Digital or 35mm color photography should always be used in condition surveys. The engineer who writes the maintenance specifications may not see the actual structure prior to writing the specification. A written report can be very detailed, yet fail to give the engineer a true appreciation for the condition of the structure. Digital photography in the report next to the written description of each structure is the best way to ensure the engineer truly understands the condition of the structure.

10.10.1 Using Survey Data for Maintenance, Planning & Asset Management

The data collected can be used to plan the ongoing maintenance for the facility or structures. Data that is recorded regularly over a period of time allows for intelligent forecasting of maintenance that may be required and to plan for future monitoring activities. When reviewing the survey data:

- Look for discrepancies in trends (e.g., year over year):
  - Improved conditions (e.g., from a “8” to a “10”)
  - Uncharacteristic change in rating (e.g., from a “10” to a “5” in one year)
- If you observe initiation of failure:
  - Forecast maintenance
- If you observe catastrophic failures:
  - Determine the proper course of action

10.10.1.1 Use the survey data to help establish an overall Asset Management Program

Key elements to include in the program could include the following:

- Meaningful yet simple element breakdown:
  - What can be painted at the same time with the same process?
- Meaningful condition rating scheme:
  - Keep it simple; a non-expert may perform the rating
  - Integrate the rating process into maintenance practices
- Access to historical and fundamental structure information:
  - Don’t overlook the value of basic information such as coating type, square footage, and last paint date

10.10.1.2 Software-based Asset Management Tools

If available, take advantage of software tools to develop and manage an effective coatings program. The tools can help keep track of the condition of a large inventory of coated structures. Based on conditions, the owner’s maintenance objectives, and expected coating deterioration rates, the software can provide a recommended maintenance painting plan, usually in order of priority to minimize coating costs. The software can:

- Store and access critical asset data
- Collect, analyze, track, and report condition data
- Forecast, recommend and plan work
- Prioritize and budget
- Measure program performance

The software can be a proprietary system, custom built system or collection of spreadsheets. In general there are three types of software tools in this area:

1. Complex, stand-alone database programs that integrate and track comprehensive data about the condition and maintenance coating history of multiple structures.
2. Generic packaged maintenance planning software where protective coatings are treated like other maintenance planning, e.g., periodic facility maintenance.
3. Unique custom packages for specific facilities. These can be built with varying degrees of complexity.

10.10.1.3 Benefits of an Asset Management Program

An asset management program can achieve several benefits that contribute to an overall decrease in the life-cycle operating costs for the facility. The management program allows the facility to:

- Develop a meaningful long-term budget
- Measure its coating program effectiveness

- Increase its intellectual capital:
  - Historical cost and condition data
  - Physical data on coated structures
- Result? Lower life-cycle coating cost

These diagrams illustrate the cost savings over 5 years of having an asset management program in place. The Coatings Condition Index (CCI) for Facility 2, with well-maintained coatings, has high CCI values and its maintenance costs per year remains relatively constant, even decreasing in year 5.

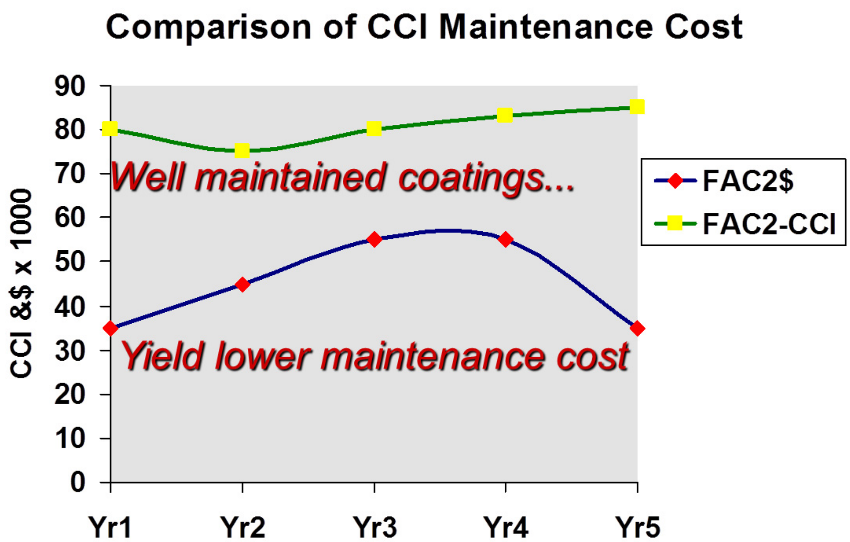


Figure 10.16 Comparison of CCI Maintenance Cost

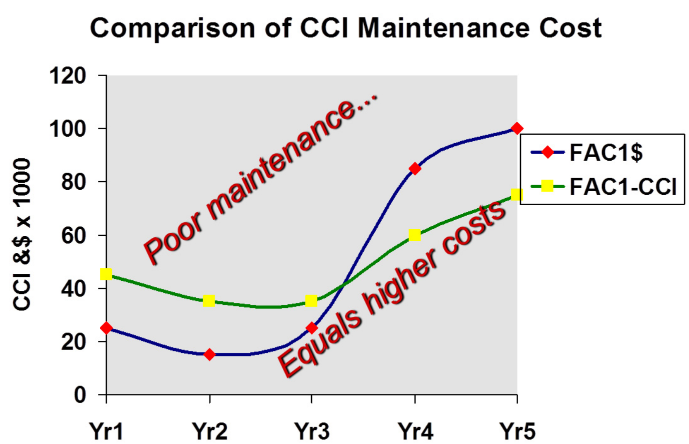


Figure 10.17
Facility 1, with lower CCI values, sees its maintenance costs increase in years 4 and 5.

Chapter 2: Coatings Overview

OBJECTIVES

Upon completion of this chapter, you will be able to:

- **OBJ 2.1:** Describe the key components of coatings
- **OBJ 2.2:** Discuss coating cure mechanisms and what curing indicates about the coating
- **OBJ 2.3:** Discuss curing processes for each coating mechanism.
- **OBJ 2.4:** Understand the difference between organic and inorganic coatings

2.1 Coating Components

Coatings are made up of a vehicle and a pigment, that when mixed in various ratios, can produce a variety of properties.

The vehicle is composed of**:**

1. Solvents
2. Binders/resins
3. Additives

The variations in coating formulation produce the ever-increasing number of generic coating types.

2.1.1 Solvents

Solvents are essential to nearly all coatings. Without a solvent, most coatings would be either a solid or a very viscous liquid too "thick" to apply using conventional spray equipment.

Solvents dissolve or carry solid particles. This reaction results in a *solution* called a coating. The total amount of solvent added should be *just enough* to change the viscosity so the coating can be applied at the specified DFT.

One key **thixotropic property** is the coating's **ability to set up and adhere to a vertical surface during curing**. In chemically cured systems (i.e., multi-component systems), the volume of the solvent influences the chemical reactivity of the coating. The solvent has to evaporate enough to allow the reacting components to come close enough to each other to complete the curing reaction. Solvents are selected based on the resins they can dissolve, i.e., suspend in the solution. Solvents commonly are organic materials such as:

- Acetones.
- Alcohols.
- Ketones.
- Esters.

2.1.2 Binders/Resins

The binder, or resin, is the film-forming component of paint and is arguably the most important component of the coating. The binder physically holds the coating together and causes the coating to adhere to the substrate. Even in coatings like varnishes with no pigments, or in ultra-high-solids, coatings with no solvent, a binder holds the coating in one cohesive unit. **The binder holds the pigments together**.

The characteristics of the binder have a large impact on the physical properties of the coating such the coating's:

- Gloss.
- Wetting tendencies.
- Durability.
- Flexibility.
- Toughness.

Binders are often referred to by how they cure. Most binders cure by solvent evaporation or chemical reactions.

2.1.3 Additives

Additives have many functions.

- **Modifiers** can impact sag resistance and control coating consistency.
- **Plasticizers** are common modifiers used with brittle coatings to improve flexibility and elongation.
- A **catalyst** increases the rate of a chemical reaction (curing).
- Special additives can improve flow and leveling properties for a more consistent dry film thickness (DFT).
- Latex vehicles use additives such as **dispersants**, **wetting agents**, **stabilizers**, and **coalescents** to maintain desired performance.
- After the coating system components are identified (resin, solvent, pigments and additives), the formulation constants must be calculated carefully. The correct amount and ratio of each is vital to achieve the desired properties.

2.1.4 Pigments

Pigments are usually inorganic compounds, but some are complex organic molecules. Pigments:

- Provide color and opacity.
- Protect certain resins and vehicles from ultraviolet light damage, improving durability.
- Support anti-fouling.
- Provide corrosion protection.
- Assist in blistering resistance.
- Provide fire retardance.

Extender pigments and fillers alter the mechanical properties of the coating, like adding strength. Fillers are a low-cost material to balance the volume of pigment in the total vehicle volume.

2.2 Curing Mechanisms

When the four basic components (solvents, binders, pigments, and additives) are put together, **a reaction occurs to form a film**.

Chemically, polymers form in several ways. The way the polymer forms is directly related to the coating cure. NACE defines curing as *the chemical process of developing the intended properties*

of a coating or other material (e.g., resin) over a period of time. Coating cure occurs when the coating solidifies to create a solid film over the surface.

The two main types of curing mechanisms are:

- **Convertible** *(Thermoset).*
- **Non-Convertible** *(Thermoplastic).*

A family of coatings usually is considered **either** convertible **or** non-convertible, but a change in formulation could make the family of coatings available in two versions, convertible **and** non-convertible. *Table 2.1* shows the properties of convertible and non-convertible coatings.

Table 2.1: Convertible vs. Non-convertible Bonding

Convertible	Non-convertible
Produced by a one-way chemical reaction	Produced by solvent or water evaporation
Cannot be reconstituted into a liquid form	Can be reconstituted into a liquid form by adding appropriate solvents
Generally are two component coatings	Generally are single component coatings
Creates a rigid network of cross-linking bonds that are not easily broken	Returns to a solid when solvent evaporates and has not chemically changed from its original form.

Chapters 3 and 4 cover classifying the coatings by their cure mechanism, either Convertible or Non-Convertible.

Table 2.2: Properties

Convertible	**Non-convertible**
• Alkyds and oil based • Polyesters and vinyl esters • Epoxy • Polyurethane • Organic zinc • Inorganic zinc • Silicones • Polysiloxanes • Galvanizing • Zinc spray	• Chlorinated rubbers • Vinyls • Emulsions /latex • Asphaltics • Acrylic Resins

2.2.1 Convertible Coatings

Convertible *(thermoset)* coatings cure by a chemical reaction called **polymerization** (the chemical combination of different monomers). This chemical reaction occurs between the polymer components of the coating that modifies the coating chemistry. The "**cross-linking**" of the components becomes the solid film. Cross-links are bonds which hold polymer chains together. Convertible coatings have strong rigid cross-links.

2.2.1.1 Convertible Processes

Several types of curing processes occur in convertible coatings.

- **Oxidation.** The solvent starts to evaporate allowing oxygen to penetrate the film. The oxygen molecules then cross-link to form bonds that hold the polymer chains together thus forming a solid film. Over time these coatings will become brittle from taking on too much oxygen. Coatings that cure by oxidation typically include alkyd-type materials.
- **Co-Reaction**. This occurs when a curing agent (hardener) is added to the coating. When the curing agent bonds with the resin it forms a three-dimensional crystalline structure. These coatings are generally two-component coatings such as urethanes, polyesters, and epoxies.
- **Heat-induced.** The reaction takes place solely by the effect of temperature without a co-reactant or catalyst. A good example is a pure phenolic coating.
- **Hydration.** Some thermoset coatings cure by hydration; they react with moisture in the atmosphere to form a film. Cementitious materials and moisture-cured urethanes cure by this process.

2.2.2 Non-convertible Coatings

Non-convertible *(thermoplastic)* coatings dry solely by evaporation of either the solvent or water (the resin is already in its final form), and there is no chemical or physical change in the nonvolatile part of the coating that forms the film.

2.2.2.1 Non-convertible Processes

The curing processes that occur in non-convertible coatings include:

- **Solvent Evaporation.** Cure is accomplished solely by evaporation of the solvent. No chemical change occurs in the binder and the wet film can be redissolved in the original solvent. Example: chlorinated rubber.
- **Water Evaporation (Coalescence).** Resin particles are dissolved in water (water is a solvent) with the aid of surfactants. When the water evaporates, the particles coalesce and form a film. Example: acrylic latex.

2.3 How Coatings Are Classified

Coatings are classified in numerous ways. The two most common ways of classifying coatings are:

- **Content:** Organic or Inorganic
- **Generic chemistry** polyurethane, polysiloxane, etc

2.3.1 Content: Organic & Inorganic

Organic coatings have a polymeric backbone made of chains of carbon-bonded molecules. In the past these coatings were made of oils, animal fats, waxes, or petroleum. Today most organic coatings are formulated from synthetic chemicals. In general, organic coatings form the bulk of the coating products in use today.

In contrast, **inorganic coatings** are made from mineral-type materials. Many inorganic coatings have backbones made from silicone. Inorganic coatings are traditionally reserved for specialized uses, including sacrificial materials like inorganic zinc, and high temperature materials.

2.3.2 Generic Chemistry

While there are different ways of classifying coating materials generically, these classifications only provide some *indication* of the properties of the coatings.

Coating are also classified by nomenclature that refers to their coating chemistry. Designations such as "alkyd" or "epoxy" are not completely definitive in describing a coating material's characteristics or performance. The chemical nomenclature typically refers only to the key functional groups or chains comprising the finished coating.

The generic chemical classifications are only *slightly* more descriptive unless you have complete knowledge of:

- Co-polymers in finished coating.
- Pigment packages.
- Molecular weight of the resins.
- Curing processes.

2.4 Other Considerations

Today, a wide range of products are labeled by their specific chemistry but they perform very differently.

2.4.1 Material Availability

Coating manufacturers can be limited to available raw materials and whatever their suppliers have on hand. Materials go through popularity phases due to the constantly changing advances in chemistry.

Between 1950–1990 there was a focus on natural resins or their modifications, such as chlorinated rubbers. The coating you buy today may still have the same name, but it is very likely to be drastically different chemically from its original formulation. Since the 1990s, advances in chemistry and changes in environmental regulation, i.e., Hazardous Air Pollutant (HAP) and Volatile Organic Compounds (VOCs), the industry has focused on innovative synthetic resins.

2.4.2 Material Costs

The cost of materials causes manufacturers to substitute cheaper alternatives when an equally good material is available. This is due to popularity phases driven by new chemical innovations. The cost is based on supply and demand which is driven by the popularity of new chemistries.

2.4.3 Material Functionality

Coating manufacturers change materials to improve the functionality of the coating. This may mean major overhauls or minor adjustments specific to the service use of the coating.

Chapter 3: Convertible Coatings

OBJECTIVES

After you complete this chapter you should:

OBJ 3.1: Have a working understanding of the uses and benefits of convertible coatings.

OVERVIEW

The ability to combine or modify coating chemistries creates an infinite number of possible types of coatings. It is difficult to classify them clearly. Classifying them by their curing mechanism presents them by their fundamental characteristics. Common types of convertible coatings include:

- Alkyds and oil based coatings
- Polyesters and vinyl esters
- Epoxies
- Polyurethanes
- Polyureas
- Organic zincs
- Inorganic zincs
- Silicones
- Polysiloxanes

3.1 Alkyds and oil bases

Alkyds are among the oldest and most basic of the paint forms. They are produced though a reaction which includes various combinations of:

- Alcohol
- Acid
- Fatty oil

The three ingredients are combined and react to create an alkyd. The term alkyd comes from the "**a**" in ***al***cohol and the "**cid**" in **a***cid*. The ratio in which these products are combined, the functional groups they contain, and the additives control its ultimate properties. The combination of the alcohols and acids form an **ester**.

This "ester" is a weak point in the polymer when in alkaline conditions (high pH).

Oxidation promotes linkage of the resin along the fatty oil chain. This reaction of oxygen with oil produces the basic chemical structure.

In general, alkyds are classified by their "oil length." Oil length typically refers to the ratio of fatty acid to resin in the alkyd, based on the total nonvolatile components. These oil alkyds are designated as:

- Short
- Medium
- Long

Long Oil Alkyds. The longer the oil length, the more oil is present. Long oil alkyds generally have an oil content of 60% or more. Oil length has an effect on the coating's solubility, viscosity, flexibility and hardness. Long oil alkyds are popular in both interior and exterior architectural paints. They are primarily used as coatings for exterior wood structures and as exterior trim enamels. Long Oil alkyds are often used in primers due to their ability to penetrate surface contaminants and light corrosion to achieve a bond with the substrate or the existing coating. These materials are much closer to oil paints than they are to the alkyds used for corrosion resistance

Medium Oil Alkyds. These are most important from the standpoint of corrosion protection. They have a wide range of properties and are common for most of the applications familiar to corrosion engineers. Medium oil alkyds have an oil content of 40-60%. While harder to apply than longer oil alkyds, the reduced oil content provides for_better corrosion resistance along with better color and gloss.

Short Oil Alkyds. Short oil alkyds have oil levels below 40%.These are primarily used for baked finishes and thus are well suited as product finishes. They have fair corrosion resistance but are limited in flexibility.

In addition to the three basic ingredients, modifiers can be added to alkyd coatings to enhance performance. Driers are commonly added and are used to drive/control oxidation. These driers include cobalt, manganese, zirconium and calcium.

Corrosion inhibitors such as red iron oxide, zinc oxide, calcium metaborate, barium metaborate and others have largely replaced zinc chromates and strontium chromates in oil base and alkyd primers.

Water Dispersible Alkyds. In order to meet increasingly lower VOC regulations some manufacturers have developed alkyd resins that are miscible in water or in water/solvent mixtures. Their use has been mainly in decorative alkyds rather than industrial high performance alkyds.

3.1.1 Special and Unique Considerations

Special consideration should be given to surface preparation when using an alkyd coating. If the surface is not properly cleaned and alkali (basic) substances remain on the surface, **saponification** can occur. Saponification occurs when a base reacts with fatty oil and forms a soap. When saponification occurs, it happens at the interface of the coating and the substrate and causes the coating to lose adhesion, which results in delamination.

Alkyds should not be applied too thickly. For the oxidation reaction to create a properly cured film, the reaction should proceed from the substrate outward. If a film is applied too thickly, the top of the film can cure more quickly than the bottom of the film near the substrate. This is because oxygen cannot reach the bottom of the film to initiate cure. The thick coating also traps solvents; their inability to escape causes surface wrinkling. This can cause adhesion and cross-linking problems.

Alkyds tend to display fewer film defects during application because of easy application. Nevertheless, inspect for film adhesion defects such as peeling and delamination, and film thickness. Alkyds also can deteriorate over time in exterior applications due to natural wear.

Since there are endless variations of alcohols, acids and fatty oils, the possibilities for creating alkyds are virtually endless. Due to this versatility alkyd costs are relatively low compared to other industrial coatings. The following are some common types of alkyds and their general properties.

3.1.2 Modified Alkyds

Alkyds can be modified with numerous other resin materials, and this creates a distinct advantage. Each of the other resins contributes some of its properties to the alkyd, which makes a versatile family of coating materials. Examples of materials that can be combined with alkyds include:

- Silicones

- Urethanes

Most of these materials are actually reacted into the basic alkyd resins and are considered copolymers.

3.1.2.1 Silicone Alkyds

Silicone alkyds are a step above pure alkyds in resistance to general weathering conditions and high temperatures.

The percentage of silicone resin compared to alkyd resin affects coating performance. Silicone alkyds combine performance characteristics from their main building blocks. Alkyds contribute to workability while silicones contribute to the following:

- Durability
- Gloss retention
- Weather resistance
- Heat resistance
- Flexibility

Silicone alkyds are increasingly used as maintenance and shipboard finishes because of these improved characteristics. Silicone alkyds also are used rather extensively for stack coatings and for similar areas where moderately high temperatures are involved. At temperatures around 250°-300° F (121° - 149°C) the silicone content should be at least 30%.

3.1.2.2 Uralkyds

Uralkyds (or urethane oils) use the reactive hydroxyl groups on the basic resin's molecule. They are reacted with toluene disocyanate or other isocyanates, which can upgrade the properties of the alkyd or oil-base coating. Commercial products contain 15% to 30% isocyanate by weight. The alkyd molecules still retain the oxidizing oil fatty acid group, so they cure primarily through oil oxidation reaction.

The reaction of the isocyanate with alkyds greatly improves:

- Abrasion resistance
- Gloss retention
- Weatherability

Uralkyds are often used to coat wooden floors because of their excellent abrasion resistance.

3.1.2.3 High Solids Alkyds

Because government regulations restrict the amount of volatile compounds that can be released into the atmosphere, resin manufacturers have an economic incentive to create high solids alkyds, waterborne alkyds, waterborne uralkyds, and epoxy esters.

Formulation variables with the newer high solids alkyd resins require very careful blending, balancing of components, and selection of driers. Reactive aluminum and zirconium driers have replaced some traditional cobalt and lead alkyd driers.

3.2 Polyesters and vinyl esters

Polyester means "many esters." There are thousands of possible esters, but only a few are used in the coatings industry. They have low molecular weights and are amorphous. They have linear polyester resins based on dihydric alcohols and dibasic acids, which are sufficiently unsaturated so they can cross-link with vinyl-type monomers.

Polyester coatings are created by the addition of an acid and a base without fatty oil. The types of acids and bases vary depending on the desired product. A strong acid is almost always added as a catalyst to the reaction. The catalyst in this case causes the solvent to evaporate more rapidly.

Certain polyesters with no strong acid catalyst will react quickly but then take several years, sometimes more than 25 years**,** to reach final cure. In general, most polyesters are convertible coatings.

There are two areas where polyester resins are used for coatings. The first is for the "gel coat" of reinforced plastics. It is generally used as the first material on the mold to provide a dense, glossy, weather, and corrosion resistant surface, which also has a good appearance. The second area where polyesters are effective is in 100% solids coatings, which have good corrosion resistance properties.

3.2.1 Special and unique considerations

Polyester and vinyl ester coatings have been used extensively for lining tank bottoms, especially in reinforced applications. They have excellent corrosion resistance for service on oxidizing materials and acids, but not for alkaline service.

While the weathering resistance of polyester resins is satisfactory, these materials are seldom used as coatings directly exposed to weathering conditions. Some polyester materials are incorporated into cements for acid proof brick and tile, and they are used particularly where oxidizing products are encountered. While both polyesters and vinyl esters are classified as 100% volume solid coatings it is common to find that wet film thickness does not equal dry film thickness, particularly in hot, windy conditions. This is due to the evaporation of some styrene from the film before it can react completely with the polyester or vinyl ester resin. Because there is some inherent shrinkage of polyester linings, they are seldom used without some type of filler or reinforcer, either a pigment type, or more often, glass fabrics and mats, or synthetic fabrics.

3.3 Epoxies

Epoxy coatings form a primary portion of industrial corrosion control coatings today. Technically, an epoxy resin is a polymer with a three-membered ring molecule referred to as oxirane or ethylene oxide. These groups are the functional groups that allow for cross-linking of the epoxy polymer with other polymers. The most common corrosion control epoxy is referred to as a bisphenol-A epoxy.

As produced, the epoxy polymer is a convertible material. To achieve the expected epoxy corrosion resistance, the epoxy is combined with suitable cross-linking agents. Common materials are tertiary amines and polyamides. Cross-linking takes place by breaking the bonds within the oxirane functional groups. The ultimate performance of the material is a function of the base epoxy resin and the curing agent. The amine's curing agents may be liquid, low molecular weight materials, or they may be high molecular weight resins, semi-liquids, with amine groups scattered over longer chain molecules, such as the polyamides. Polyamides (compared to the low molecular weight amines) are very large, complex molecules with a certain amount of amine sites for cross-linking the epoxy polymers but also with a large internal chemical makeup. The difference in these two curing agents (polyamides and amines) is responsible for many properties of the final paint.

In general, the smaller, lower-weight materials are more mobile and reactive. They cure the paint much more rapidly, provide higher cross-linking, and also reduce the free volume within the finished, thermoset resin. The larger curing agent is easier to apply (the curing rate is slower so the paint does not cure immediately upon mixing), more flexible, and still provides adequate corrosion resistance for most applications.

Epoxies are generally used as primers because of better adhesion and compatibility. They may also be used as low viscosity penetrating sealants, intermediate coats to provide build, tie coats, chemical resistant finish coats, durable high wear non-skid coatings, and linings.

3.3.1 Modified Epoxies

Common types of epoxies include:

- Polyamine Epoxies
- Polyamide Epoxies
- Novolac Epoxies
- Bisphenol A and Bisphenol F Epoxies
- Phenolics
- Waterborne Epoxies
- Others

3.3.2 Polyamine Epoxies

The aliphatic amine-cured epoxy systems form very hard, adherent coating systems that are very chemical and corrosion resistant. They are tightly cross-linked. They have:

- Excellent alkali resistance
- Excellent salt resistance
- Good water resistance
- Good solvent resistance

They are used as protective coatings in many highly corrosive conditions. Their weathering resistance, however, is not great since they tend to chalk easily.

These principally corrosion resistant epoxy coatings are formed by the use of the amine epoxide reaction. In this case, the terminal epoxy groups on the basic resin react with the active hydrogen groups on the primary and secondary amines. This reaction takes place readily at room temperature. Depending on the amine, the reaction can be almost explosive or it can be quite slow. These reactions are temperature sensitive; therefore the reaction takes place rather slowly at low ambient temperatures or, in some cases, not at all. At higher ambient temperatures, the reaction occurs much more quickly.

3.3.3 Polyamide Epoxies

The reaction of the basic epoxy resin with the polyamide curing resins forms the basis for one of the most widely used corrosion-resistant epoxy coatings at the present time. There are a number of different viscosities and molecular weights of polyamide resins, and they can be used in different quantities with different epoxy basic resins. The polyamide epoxy coatings are considerably softer, more resilient, and more flexible than the amine-cured epoxy coatings.

Polyamides have excellent alkali resistance, but their acid resistance is not as satisfactory as the amine-cured epoxy coatings. The weather resistance of the polyamide epoxy coatings is considerably better than that of the amine-cured type. Thus, the former materials are primarily used for exterior atmospheric corrosion resistance, while the latter are used to a greater extent as tank linings and interior coatings for acidic corrosion conditions.

The polyamides have lesser solvent resistance than the amines. The polyamide epoxy coatings cure readily at room temperature and, as commonly formulated, have good pot lives for easy application. The polyamide resins with large molecules form a more bulky curing agent than the amines. They are packaged in two containers on an almost equivalent volume basis for the epoxy resin solution and the polyamide resin curing agent. This provides easy handling in the field during application.

3.3.4 Novolac Epoxies

The increasing purity and aggressiveness of solvents and chemicals has produced a need for even higher cross-link densities than possible with traditional epoxy coatings. A popular answer to this problem is the use of epoxy novolac resins.

Aliphatic amine-cured resins of this type are highly resistant to most solvents (including ketones, chlorinated hydrocarbons, and lower alkyl alcohols). They resist mineral acids such as hydrochloric, hydrofluoric and sulfuric acid, and alkalis such as liquid ammonia. Some cross-linked systems are even resistant to methanol (especially when post-cured). Although many of these systems will ambient cure, all of them benefit from post-curing with heat.

3.3.5 Bisphenol A versus Bisphenol F Epoxies

Bisphenol A (BPA) epoxies resins are used as coatings on the inside of almost all food and beverage cans. It has excellent anti-corrosion properties, and provide a combination of toughness, adhesion, formability, and chemical resistance. The use of BPA has become highly controversial in recent years due to its high potential for negative health effects and many countries have banned its use in food and beverage containers.

Low molecular weight bisphenol F epoxy resins offer some advantageous properties, particularly for aggressive corrosion conditions. They give more highly cross-linked polymeric matrices than do bisphenol A systems of similar molecular weight, thus yielding a coating with somewhat better solvent, heat, and chemical resistance. They are available as low VOC coatings below the threshold limits of 250 g/L (2.1 lbs/gal).

3.3.6 Phenolics

Many of the epoxy-phenolic coatings are baked coatings requiring several hundred degrees of temperature to properly cure.

There are also phenolic coatings available that will cure at substantially lower temperatures. They are very slow to cure at ambient temperatures; however, at approximately l40°F (60°C), they do cure to a chemical resistant coating with very nearly the equivalent resistance to baked coatings.

Many of these coatings are used for immersion in solvents, saltwater, and particularly for the lining of tank cars or barges transporting concentrated sodium hydroxide solution. These epoxy-phenolic coatings or linings provide excellent chemical and corrosion resistance.

3.3.7 Waterborne Epoxies

A great deal of research has been done on waterborne epoxy resin systems as a result of regulations limiting the use of organic solvents in coatings. Waterborne epoxies have lower VOC emissions than some solvent-based epoxies. These coatings are usually two package epoxy-polyamide systems. The epoxy component is an emulsion, based on a proprietary mixture of a liquid epoxy resin and an aliphatic epoxy monomer. The low viscosity, imparted to the epoxy resin by the aliphatic diluents, ensures proper coalescence of the resin co-reactants during film formation as the water evaporates.

The polyamide curing agent component is supplied in a mixture of a high-boiling aromatic solvent and a hydroxyl-free water miscible solvent such as ethylene glycol monoethylether acetate.

As in the case of a conventional two package epoxy system, the curing agent component is packaged separately.

Weather conditions with average humidity and temperatures near 59°F (15°C) allow water based type coatings to provide good service, even under some reasonably severe corrosion conditions.

Many of early sales of waterborne epoxies were for commercial and institutional concrete structures, due to flash rusting and deficient performance on steel versus solvent-borne epoxies.

Newer resins, including water miscible polyamides (with and without external emulsifiers of the nonylphenol ethylene oxide type) have provided better performance.

3.3.8 Coal-Tar epoxy

Coal tar epoxies are a combination of the basic epoxy resin with coal tar. The coal tar is in the form of a semi-liquid pitch and is blended with the basic epoxy resin and solvent. The curing mechanism for the coal tar epoxy is the amine reaction with the terminal epoxide groups on the epoxy resin. There is a distinct difference in effectiveness between many of the coal tar epoxies produced around the world because of the source of the coal tar.

A combination of the two materials appears to combine the good properties of both the epoxy and the coal tar to form a superior water and saltwater-resistant coating. It is not often that a combination of two widely different materials such as epoxy and coal tar result in a finished material that is superior to either when used alone.

The combination is resistant to a wide variety of aqueous conditions as well as to materials such as hydrochloric acid, sodium hydroxide, and sour crude oil. The combination of the two materials resists sagging up to 200°C (392°F) and is less brittle and more resistant to impact than unmodified coal tar alone. The aliphatic amine provides a less permeable, tough, adherent coating.

The coal tar epoxy also may be mixed with the polyamide curing agents to form a much more resilient, somewhat softer coating, also with good adhesion. The polyamide coal tar epoxy has excellent water resistance.

However, the polyamide coal tar epoxy also has some serious drawbacks. It tends to delaminate between coats for any number of different reasons. Water or moisture on the surface, too long a period between coats, and even exposure to strong sunlight for even a few hours will cause delamination of the following coat.

Coal tar epoxy coatings were used extensively up until the 21st century. Health concerns over some of the coal tar constituents as well as their naturally dark color that hampered inspection in tanks has helped phase out these materials. Their primary legacy is the performance standards they established for other coatings to follow.

3.4 Polyurethanes

Polyurethane coatings contain resins made by the reaction of isocyanates with hydroxyl-containing compounds (e.g., water, mono- and diglycerides made by the alcoholysis of drying oils, polyesters, polyethers, epoxy resins, acrylics, and numerous others). Wherever there is an active hydroxyl group, the isocyanate will react with it.

Both aliphatic and aromatic polyurethane coatings are commonly used in corrosion resistant coating systems. The aromatic polyurethanes are more chemical resistant while the aliphatic polyurethanes have better color and gloss retention. As a result the aliphatics are mostly used as a finish coat over other organic coatings in the system.The reaction of isocyanate with hydroxols is the primary basis for all of the various isocyanate or urethane coatings.

As outlined by ASTM D16, *Standard Terminology Relating to Paint, Varnish, Lacquer and Related Products*, there are six different urethane coating types.

3.4.1 Type I: One Package Pre-reacted Polyurethane Oil

In the case of the oil-modified type, alcoholysis products of drying oils are reacted with isocyanate. This forms a polymer, with the unsaturated drying oils as part of it. These coatings contain no active isocyanate at the time of application, since it is completely reacted during manufacturing.

They look and handle like high-quality marine spar varnishes. They are finding wide use as clear wood finishes, floor varnishes, and spar varnishes. They are very abrasion resistant and have good gloss retention and weatherability.

3.4.2 Type II: One Package Moisture Cured Polyurethane

Moisture reactive polyurethanes are formed with resins having a terminal isocyanate group in the molecule. After application, the prepolymer reacts with moisture in the atmosphere to form the final cross-linked coating.

In general, higher molecular weight dialcohols increase flexibility and abrasion resistance at the expense of hardness and some chemical resistance. Increasing triols imparts additional toughness through the cross-linking.

Many of these single-package polyurethanes are actually mixtures of diols and triols in order to arrive at the proper combination of hardness, flexibility, and toughness.

The urethane prepolymer coatings are useful because of the combination of properties that are possible in a single coating. In particular, the abrasion resistance is outstanding, combined with flexibility, hardness, and tensile strength. The chemical and solvent resistance of the moisture cure polyurethanes is also good.

The fact that these urethane coatings are cured from moisture in the air is sometimes also a disadvantage. The curing time is reduced rapidly at high humidity, while it is lengthened to the point of no cure if the humidity is very low. This must be taken into consideration whenever coatings of this type are being used.

Because of the cross-linking and increase in solvent resistance of these materials, recoating should be done before the polymer reaches its complete cure. This can occur within 24 hours after application, although formula modifications exist for longer recoat times. Otherwise, the coating will require abrasion of the surface in order to secure intercoat adhesion.

During the 1990s, special systems were developed incorporating zinc, micaceous iron oxide, and coal tar pitch that gained wide usage as repair systems on bridges and marine vessels.

3.4.3 Type III: One Package Heat Cured (Blocked) Urethane

With the blocked urethane coatings, the prepolymer is used as previously indicated. In this case, however, it is formed into an adduct by reacting the isocyanate groups with a material such as phenol, which makes it unreactive at room temperature.

This material can be packaged in one can with other polyols and pigments with good package stability. The curing of the blocked resins, however, requires heating, and a threshold temperature must be reached before any curing can take place. In the case of phenol-blocked resins, this is approximately 140°C (284°F). Cure may be greatly sped up by use of an appropriate catalyst. Because of the heating required, these materials are usually not used for anticorrosive coatings in the field. They are primarily used as product finishes.

3.4.4 Type IV: Two Package Catalyst (Moisture Cure With Co-reactant)

In the prepolymer plus catalyst coating, the isocyanate prepolymer is used with a reaction essentially the same as outlined under moisture cure, with the exception that separate catalysts are mixed with it to increase and accelerate the cure. The catalysts are metal dryers of the same type used for drying oils or some of the amines such as diethanol amine.

3.4.5 Type V: Two Package Polyol (Isocyanate and Containing Reactive Hydrogen)

In the case of the two package coatings, the prepolymers differ from those used in the moisture cure product by having a relatively low molecular weight. They are reacted with relatively low

molecular weight polyols, such as alcohols, to form adducts. The adducts then form one part of the two-can system.

The curing is obtained from the second component, which can be any of the polyols that have been considered in the other polyurethane coating types. The more hydroxyl groups on the polyol, the greater the cross-linking. This produces a somewhat less flexible film, but with higher chemical and solvent resistance.

3.4.6 Type VI: One Package, Nonreactive Lacquer Polyurethane

Urethane lacquers are a rather recent development, particularly the non-yellowing type. They dry by simple solvent evaporation. The urethane lacquers are fully polymerized, thermoplastic coatings, relatively high in molecular weight, and dissolved in suitable solvents.

They have relatively low solids; however, they produce films of a number of different consistencies ranging from very hard to soft and rubbery. Even rubber itself can be coated and protected with these materials. In fact, most of the exterior flexible or semi rigid articles for automotive use, such as rubber bumpers, are coated with these urethane lacquers.

3.5 Polyureas

Polyureas are often confused with polyurethanes, but they are very distinct products. Polyureas are formed by the reaction of an isocyanate with an amine polymer.

As with polyurethanes, there is a wide variety of isocyanate and amine resins that can be used to formulate a range of products. In particular, the reaction speed of the amine with the isocyanate is much faster than the reaction of the same isocyanate with a hydroxyl terminated monomer. All things being equal, polyureas can be formulated to cure much more quickly than polyurethanes.

There are also hybrid polyurea / urethane products in which an isocyanate is used to cure both amine and hydroxyl terminated monomers in the same product. The percentage and types of specific resins can be selected to enhance various properties.

Polyurea products are usually high solids products, applied using plural component equipment because they are too reactive to pre-mix and apply. Their typical gel time can be as fast as 3 seconds. Very soon after application the coating will begin to solidify and set up. This quick set up time allows for very high build of these formulations in successive passes with the same application gun. Application can extend beyond 1-inch thick.

Given the quick reaction time, polyureas are generally considered less sensitive to airborne moisture than polyurethanes — the presence of excess moisture in the air can interfere in the intended curing reaction of the polyurethanes. However, polyureas should never be applied to wet substrates.

The fast reaction time of polyureas generally means that they do not wet out the surfaces of the substrates as well as other coatings. They generally require a primer such as conventional polyurethane to achieve suitable adhesion.

Given their extensive cross linking they will tend to form very hard coatings, so they are often used for high abrasion, high wear areas as well. These same coatings will have low flexibility and elongation. For some applications, such as flexible structures, the coatings need to be formulated with a slower curing agent that also provides better flexibility.

As with polyurethanes the polyureas formulated with aliphatic isocyanates vs. aromatic isocyanates will tend to have better weathering resistance (UV resistance).

3.6 Organic Zincs

The main purpose of a zinc coating is to provide some level of cathodic protection in addition to providing a barrier.

In an organic zinc coating, zinc dust/particles are loaded into a designated organic coating type. The problem with organic zinc coatings is that the zinc particles are heavy compared to the rest of the materials and settle to the bottom. It is critical to make sure that the coating is mixed well and homogenized. As long as the correct particle ratio of zinc is maintained, the coating will provide the intended amount of cathodic protection.

The most outstanding characteristic of organic zinc rich primers is their compatibility with both organic and steel surfaces. This is extremely important in coating repair and may be important during original construction where many different types of surfaces are involved, which all require excellent corrosion protection.

Organic zinc rich coatings may extend from bare steel out over various primers and topcoats (organic or inorganic) and provide adhesion to each surface. They should be compatible with oleo resinous topcoats as well as synthetic resin types, which is not possible with inorganic zinc coatings.

Due to the various organic binders used, the coating can be fast or slow drying, and curing conditions can vary widely. A binder in an organic zinc rich primer may be more or less chemically resistant, depending on the binder and its use requirements. Chlorinated rubber, epoxies, polyurethanes, or vinyls provide chemical resistance. Silicones provide weather and temperature resistance. Epoxy esters with zinc fill are used primarily as cold galvanizing compounds for the touch-up and repair of welds in galvanized steel.

Organic zinc rich coatings can sometimes tolerate varying degrees of surface preparation, but inorganic zinc always requires at least NACE No. 2 near white surface preparation.

3.7 Inorganic Zincs

Inorganic zinc (IOZ) primers are probably the most widely used primers for steel structures in the world. Whether composed of sodium silicate, potassium silicate, lithium silicate, colloidal silica, or hydrolyzed organic silicate, they are reactive materials from almost the moment that they are applied.

Inorganic zinc coatings are in a state of constant change. While the degree of change depends to a great extent on the atmospheric conditions, a slow continuing reaction takes place up until the time when the zinc in the coating has nearly been consumed in protecting the steel substrate. In certain cases, the surface of inorganic zinc coatings can become inactivated by the accumulation of zinc salts to the point that the coating becomes an inert barrier film, rather than one that protects by cathodic protection.

Inorganic zinc coatings are composed of powdered metallic zinc, mixed into a complex silicate solution. The silicate chemistry is the key to the reactions and to the cure that takes place within the inorganic zinc coating.

The silicate matrix is a network of silicon/oxygen bonds. The terminating hydroxyl groups on each silicon can be continually cross-linked with additional silicone/oxygen groups in the presence of the correct chemical conditions. The silicate matrix holds the zinc loading together in intimate contact with each zinc particle and with the substrate.

The amount of cross-linking is directly proportional to the type of silicone-oxygen bonds available to be made within the reaction with the silicate solution. There are two key types of inorganic zinc coatings.

The original products were called post-cured inorganic zincs (Type 1-A). The coatings were formed by a basic zinc rich binder, which was allowed to dry, but the coating was not completely cured as it remained partially water soluble.

The coating was post-cured by applying an acidic, amine phosphate salt. This product was a catalyst which allowed the remaining silica groups in the matrix to “open up” and react with the zinc which made the silica matrix insoluble. There was a residual salt on the surface that was then

washed away to allow for overcoating. This product had excellent corrosion control but was somewhat difficult to apply.

Now there are both solvent-borne and waterborne products (Solvent-borne ethyl silicate) (Type 1-C) is the most widely used type. A new type of product was developed — a water based (Type 1-B) sodium, lithium, or potassium silicate product. This breakthrough product enabled a less alkaline product when the coating dried through water evaporation. Under this less alkaline condition, the zinc in the coating could naturally react with the silicate to complete the reaction and cure the coating.

Solvent borne inorganic zincs cure through a reaction of the silicate with moisture from the atmosphere so they cure very slowly when the relative humidity is less than 50%. Water borne inorganic zincs cure through a reaction of the silicate with carbon dioxide from the atmosphere so they cure well at relatively low relative humidity but very slowly at high relative humidity. In both cases cure is retarded when the ambient temperature is below 50^0F (10^0C).

One of the most significant properties of both the solvent and waterborne inorganic zinc coatings is its cathodic protection. The inorganic matrix is conductive and allows the zinc to go into solution in a controlled manner, making it anodic to steel and providing cathodic protection to the steel/substrate.

In addition to superb cathodic protection, inorganic zinc coatings offer other benefits. For instance, they provide extremely good chemical resistance compared to metallic zinc. They also are completely impervious to organic solvents, even particularly strong solvents. They also are unaffected by gasoline, diesel oil, lube oil, jet fuel, and many similar refined products. Therefore, they may be used alone or in connection with topcoats in continuous service exposure to such chemicals. Inorganic coatings also have excellent abrasion resistance, fire resistance and friction characteristics.

Because of their excellent adhesion, combining both mechanical and chemical adhesion to steel, inorganic zinc coatings make an excellent base for organic coatings. Over steel, they reduce both the undercutting and blistering that might occur if organic coatings were applied directly to the steel surface. This same characteristic (providing an excellent base coat for organic coatings) also applies to many organic coatings subject to cathodic protection.

The efficiency of inorganic zinc products in providing cathodic protection is directly related to their zinc loading. Products with the highest levels of cathodic protection typically have greater than 80 percent zinc in the dry film. Less expensive formulations with lower zinc levels are available. Some products also use a less expensive filler material in place of the zinc that is still conductive but reduces the total life of the coating. Inorganic zinc primers require constant agitation during application to keep the zinc in suspension.

3.8 Silicones

Silicones are formed by chemical modification of quartz or sand. As inorganic coatings, they may be thought of as hybrids of glass and organic resins. They have much the same inertness as glass but can be incorporated into coatings in the same manner as organic polymers.

A silicon-based polymer primarily has silicon-oxygen-silicon linkages. This is the same chemistry introduced as the binder for inorganic zinc coatings. The silicon atom is tetra-functional in the same way that the carbon atom is, and one or more of the attached functional groups may be based on organic carbon.

The organic groups that have the most desirable properties when combined with the silicone are the methyl and phenyl groups. High phenyl-containing resins tend to have better heat and oxidation resistance than the methyl substitutes. Most of the silicone resins used in the coatings industry are a combination of the two, forming methyl phenyl silicone polymers. Properties can vary widely, depending on the ratio of the methyl and phenyl groups.

A silicone polymer may have a number of different organic groups attached to the silicon atoms. As the number of organic groups on the silicone polymer increases, the resin becomes softer, more flexible, somewhat slower curing, and more convertible.

Most of the silicone resins are dissolved in hydrocarbon solvents. The solvents are usually included in the manufacture of the resins to improve control of the hydrolysis of the basic silicon molecule and prevent gelation. Modified silicone resins generally require high temperature cutting to obtain their optimum characteristics. They do, however, respond to catalysts. Zinc catalysts, such as zinc napthenate, are used most often and yield good results.

Silicones are copolymerized with other organic polymers in order to improve the organic material's properties of heat resistance and weathering. In some cases, silicones can be co-blended with other organic materials. Copolymers are made from several silicone intermediates, which have hydroxyl or methoxy groups attached to the silicone molecule. These are the groups that can react with organic polymers that have active hydroxyl groups.

The organic materials which form satisfactory copolymers with silicone intermediates are alkyds, polyesters, polyols, epoxies, epoxy esters, uralkyds, and acrylics. The copolymers have increased heat and weather resistance over and above the organic coating material alone.

The silicone organic copolymers cure into a final coating using the same mechanism as the organic part of the copolymer. This has been shown previously under alkyds, where the silicone alkyd is cured by the oxidation reaction of the oil modified alkyds.

Silicone copolymer maintenance coatings generally have good color and gloss retention, and tend to chalk at a much slower rate than the organic finish alone. Improved water and corrosion resistance is also common. The improvement is proportional to the percent silicone incorporated into the structure, which also proportionately increases cost.

One of the popular uses of the silicone copolymers is for coil coating. This is where strips of metal are coated in a continuous process, rolling from a coil of metal passing through the coating and baking process, and then recoiled within a minute to a minute and a half. The temperature in this case is a high bake 315.55°C (600°F). The materials used are silicone-polyester copolymers and are generally made with the linear silicone intermediates for flexibility.

Silicones have many beneficial properties such as good adhesion to most substrates, chemical resistance to water, mild acids and alkalis, heat resistance to very high temperatures (greater than 550^{o}C [932^{o}F]), resistance to UV and thermal change and excellent electrical properties. These qualities make them good candidates for corrosion resistant coatings. On the other hand, there are areas where silicones fall short. Silicone materials tend to be very soft and thus have poor abrasion resistance.

3.9 Polysiloxanes

Polysiloxanes have polymeric structures that contain repeating silicon/oxygen groups in the backbone, side chains, segments, or cross-links, regardless of substitution on the silicon atom. This chemistry has been used to create compositions having excellent thermal and chemical resistance, extended weatherability and appearance over the traditional silicone resin. In general, polysiloxane coatings cure at ambient temperatures and have high solids and low VOC, excellent temperature and UV resistance, and good resistance to acids and solvents. Compositions containing pure polysiloxane resin networks have been formulated that provide heat resistance in excess of 1,093°C (2,000°F). Typical formulations contain micaceous iron oxide (MiOx) as the major filler component. The resin/pigment ratio is as close as possible to the critical pigment volume concentration (CPVC) and the product cures by hydrolytic polycondensation at ambient conditions without any baking.

This technology can be used in an essentially inorganic formulation that behaves like a zinc silicate without the acid-exposure and chemical-reactivity limitations of inorganic zincs. Tank lining formulations are possible, which include a broad range of resistance to solvents, organic acids, and mineral acids,.

By using appropriate blends of silicone intermediates and oxysiloxane cross-linking agents, topcoats similar in appearance to polyurethanes have been formulated. Polysiloxane acrylic topcoat blends have been formulated which meet or exceed the ultraviolet resistance properties of polyurethanes.

Initially the polysiloxane finish coats were modifications of an epoxy resin. The so-called second generation polysiloxanes were modifications of an acrylic resin. Both of these are two-component products. Now there are single-component polysiloxanes based on a modification of a limited number of organic monomers.

3.10 High Solids

The most common high solids materials in use today are based on epoxy, polyurethane, and polyurea materials. Epoxy materials have a long tradition of corrosion control applications.

High solids epoxy materials are typically based on the standard resin products synthesized by the reaction of bisphenol A with epichlorohydrin. Other improved systems are based on bisphenol F (novolac) resins. These products typically offer higher functionality versus the bisphenol A materials and thus more opportunities for high cross-linking. This can produce materials with higher chemical and temperature resistance; however, increases in cross-linking can also lead to less flexible films.

High solids novolac coatings are often heat-cured (i.e., a liner). This improves the chemical resistance of the materials by increasing the cross-link density. The time to complete the heat curing process with high solids materials can be 5 to 10 times less than more traditional solvent-containing coatings.

High solids epoxy films can be applied in a range of 375 to 800 µm (15 to 32 mils) in a single coat. Multiple coats may be applied over previous coatings. The epoxy materials can be pigmented with a wide range of materials to enhance chemical and abrasion properties.

Compared to the polyurethane materials, the epoxy materials will have less resistance to sunlight. For underground applications, epoxies will generally have better resistance to cathodic disbondment, an advantage over the polyurethane materials. In certain chemical and solvent applications, the epoxy materials will also outperform polyurethanes and ureas.

Polyurethane and urea materials represent the fastest growing segment of the high solids market. This probably is a result of the wide range of industrial uses of these very versatile materials and the many ways the final coating product can be tailored. NACE publication 6A198, "Introduction to Thick-Film Polyurethanes, Polyureas, and Blends" provides a good introduction to many of these materials.

The publication discusses the basic chemistry of polyurethanes and urea materials and discusses the basic polyol or amine reactions with isocyanate resins. The publication also provides typical performance parameters and specification requirements for these products. Table 3.1from the publication is reproduced below and illustrates the wide range of application for these products.

Table 3.1: Applications Using Thick Film Polyurethanes, Polyureas, and Blends

Transportation • Automobiles • Boats • Trucks • Railcars **Industrial Maintenance** • Walls in structures • Tanks • Pipe linings • Metal buildings **Floor Protection** • Floor toppings **Containment/Membranes** • Primary containment • Secondary containment	**Protection of Polyurethane Foam on**: • Roofing • Tanks • Piping • Freezers • Fish/ship holds **Concrete Protection** • Containment • Waterproofing • Floor maintenance • Linings • Traffic decks **Abrasion Resistance** • Chutes • Hoppers • Conveyors • Equipment • Spiral separators	**Structural Spray-in-Mold** • Bumpers • Side panels • Spoilers • Go-cart bodies • Snowmobiles **Expanded Polystyrene** • Architectural shapes • Flotation devices **Maritime/Marine** • Fenders • Buoys • Inflatable boats • Tankers • Offshore rigs • Ballast tanks **Sport Market** • Running tracks • Resilient gym floors • Water-park slides

3.10.1 Characteristics

The basic chemistry, curing reactions, and physical chemistry aspects of 100 percent solids materials are similar to the more common solvent based materials. In solvent based materials, the choice of solvent is designed to bring the mixed product to an acceptable viscosity for application, control drying time (and its associated film build properties), and provide a mobile medium where the chemically reacting species can come in contact with each other to complete the cure.

In high solids coatings these same properties are controlled (in the absence of an added solvent) by selecting lower molecular weight resins to increase their mobility, and molecularly smaller, highly reactive, and highly functional curing agents. These concepts are needed because, in the absence of a solvent, the ability of more traditional resins and curing agents to interact is reduced.

While rapid cure may create challenges in the formulation and performance of the product, it does offer a tremendous application and production benefit. Traditional solvent based coatings take a considerable amount of time to cure. In multiple coat systems, this can add days to the production process. A rapid cure can save considerable work time.

The coating chemistry also allows for the development of high and exceptionally high build coatings (coatings exceeding 1 inch in thickness) in continuous applications that would be

impossible with solvent based materials. The presence of the solvent would cause sagging and would cause poor performance in any “cured” coating — residual solvent is usually a hydrophilic material that often leads to premature coating failure. Therefore a formulator of 100 percent solids materials has to be very careful in balancing all of the desirable properties versus the undesirable side effects.

High solids coatings and linings have received considerable interest in the past several years. The growing use is primarily attributed to the environmental regulation of solvent emissions in surface coating operations. These materials generally meet the most stringent regulations.

In addition to meeting these regulations, the products are finding increased use in the marketplace as the product can be tailored to specific applications by controlling properties such as film build, hardness, and cure rate. Each of these properties can be individually controlled to provide choices not previously available in solvent based coatings.

The term high solids coatings is perhaps a misnomer. The name suggests that there is little to no solvent added to the coating material. There is some solvent in the formulations. These traditionally multi-component materials, however, give off only trace emissions upon curing.

The basic building blocks of these coatings are not all new. The conceptual technology is more than 50 years old and derives from multi-component products from the adhesives industry. The technology did not take off previously because it did not have an “environmental” driver. Also, there was no practical equipment to apply high solids materials. These two factors are more recent developments that have spurred growth.

For corrosion control applications, high solids products are finding favor as linings since they can support high service temperatures (in excess of 132.22^{o}C [270^{o}F]), have high abrasion resistance, and can be support a range of immersion and exposure conditions.

As bonded coatings they are also more compatible with the precepts of cathodic protection since they are less likely to shield cathodic protection current from reaching substrates as compared to form-in-place or welded linings.

3.10.2 Key Issues / Concerns

While conceptually simple, high solids materials create their own unique set of challenges and opportunities. Highly reactive curing agents lead to rapid curing of the coating. This is perhaps fine when the product is on the intended surface, but it can begin to cure at the point of mixing.

Thus, the pot life of these materials can be drastically reduced. This creates application challenges. The rapid cure also limits their time and ability to always wet surfaces. Solvents are more likely to wet surfaces versus resins because of their lower surface tension. These factors can ultimately affect coating adhesion.

Fast curing rates with poorly formulated high solids materials can also reduce corrosion resistance. If the coatings components’ mobility is substantially reduced before the coating is fully cross-linked, the resultant coating can have many micro pores that increase the ability of ionic species and oxygen to penetrate the coating and lead to substrate corrosion.

The fast cure rate also can impact certain appearance factors such as low gloss coatings. Generally, coating gloss is controlled by pigment loading and the ability of the pigment to settle properly in the resin. Rapid setting coatings are generally higher in gloss as the high rate of film cure impacts the ability of the pigment to properly disperse. Such properties can be of aesthetic importance in many applications.

3.10.3 Application

Selection of application methods and equipment depend on the coating to be applied. Alkyds, epoxy esters, single pack urethanes, and other low viscosity materials can be applied by brush and roller. The most common method of application for industrial coatings projects is airless spray. The more sophisticated coatings that are 100% solids and require no induction time are applied by

plural component airless spray equipment. Often these materials require heat to lower the viscosity so the materials will flow and form a good film. Plural component units with heaters are utilized for this type of application. Plural component airless spray units meter the components to insure that the proper mix ratio of one component to the other is maintained during application. Some units have fixed ratios such as one to one and others are adjustable from one to one to eighteen to one. Some materials such as polyureas react so quickly that they cannot be mixed in a manifold mixer or mixing block before going through the gun. They require setups with dual tips so that the components mix outside the fluid tips of the gun just before they hit the surface.

Plural component airless spray units are complex machines and require extensive training of the applicators to learn to use them correctly. Proper application of the materials is critical to achieving a successful coatings project. When the materials are not applied according to the manufacturer's instructions a premature failure is often the result.

Chapter 4: Non-Convertible Coatings

OBJECTIVES

Upon completion of this chapter, you will be able to:

OBJ 4.1: Recognize the uses and benefits of the non-convertible coatings presented in this chapter.

This chapter will present non-convertible coatings.

4.1 Non-Convertible Curing

4.1.1 Non-Convertible Processes

The curing processes that occur in non-convertible coatings include:

- Evaporation:
  - Solvent
  - Water (coalescence)
  - Heat Induced/Fusion

Often a family of coatings will be considered either convertible or non-convertible, but a change in formulation could make the coating available as either.

Since it would be impossible to talk about every coating, this chapter will address **Non-Convertible coatings, concentrating** on the following generic coating families and their properties.

- Chlorinated rubbers
- Vinyls
- Asphaltics
- Acrylic Resins

4.2 Chlorinated Rubbers

Chlorinated rubber coatings consist of natural rubber reacted with chlorine. This forms a very hard resin product that lacks the usual elastic and resilient characteristics of rubber products.

The coating has a specific gravity of 1.64, which is almost twice that of pure rubber. It is odorless, tasteless, and nontoxic, and will not support combustion or burning.

Rubber is made up of isoprene units. The chlorine content must be high enough to assure optimum stability, compatibility, and resistance to fire.

4.2.1 Benefits

Chlorine-containing organic chemicals generally have very good chemical-resistance. The amount of chlorine in the molecule is substantial. This and its saturated carbon bonds give its good chemical resistance.

Fully chlorinated coatings are primarily used in the chemical and marine industries, and in coating concrete swimming pools.

As chlorinated rubber topcoats, they also provide a very good maintenance coating. They are hard, tough, and chemical resistant; they have good resistance to extended weathering; and they can be readily repaired and recoated.

The percent solids in the coating are relatively low, providing coatings of from 1 to 3 mils thick per coat. Low molecular weight resin modifiers create the best chemical and corrosion-resistant coatings.

4.2.2 Cautions

To be effective, chlorinated rubbers must be modified by other resistant resins to obtain higher solids and to decrease brittleness and increase adhesion. The chemical and water resistance of chlorinated rubbers depend on the type of modifier used.

Alkyd or oil-base modifiers plasticize the chlorinated rubber very well, but the oil reduces corrosion resistance.

Boiling water or steam is destructive to chlorinated rubber and is not recommended for coating applications which require durability under these conditions. In spite of this, chlorinated rubber has a low water absorption.

In the absence of sunlight, aging has very little effect on chlorinated rubber. Pigmented compositions are durable in the sunlight; however, sunlight causes both discoloration and embrittlement in clear, unstable films.

4.2.3 Four Categories of Chlorinated Rubbers

Category One contains a high proportion of chlorinated rubber (50-60%) modified with nonreactive resins and plasticizers. These nonreactive materials are most often highly chlorinated materials (e.g., chlorinated paraffin), and this category is often called an all-chlorinated system. These materials are used when maximum chemical or flame resistance is needed.

Category Two differs in that the nonreactive resin or plasticizer is replaced with an alkyd or an oleresinous varnish. The chlorinated rubber content remains high; but, some of the excellent chemical resistance is sacrificed. Corrosion resistance is good and adhesion, weatherability, and ease of application increase.

In **Category Three**, the primary ingredient is alkyd resin with the chlorinated rubber fortifying the alkyd. These are sometimes called *chlorinated rubber fortified alky*ds. They have good weatherability, adhesion, gloss, and brush ability, plus some improved chemical and water resistance over the alkyd alone.

Category Four has both the chlorinated rubber and alkyd substitutes modifying another polymer. These products usually are specially formulated for a very particular application and not widely used.

Common problems found in all four categories of chlorinated rubbers include:

- Dry spray during application during hot, dry weather
- Poor chemical solvent resistance
- Relatively high VOCs

4.3 Vinyls

Theoretically, a vinyl resin is formed by polymerization of compounds derived from ethylene. <u>Vinyl polymer offers excellent chemical and age resistance</u>.

The term “vinyl resin” is limited to:

- Vinyl acetate
- Vinyl chloride-vinyl acetate copolymers
- Other similar copolymers

Vinyl resins are physically strong and resistant to a wide range of chemical reactions, such as those involving acids, alkalis, and many salts. These vinyl resins have a broad chemical resistance when compared with the more common coating polymers.

4.3.1 Beneficial Properties of Vinyl Coatings

Vinyls have beneficial properties which are important to corrosion engineers:

4.3.1.1 Film Formation

Vinyls can form a homogeneous, tight film over a surface. The film formed by the vinyl resins is different from other coating materials because it is pre-reacted or polymerized and does not go through oxidation, chemical reaction, or other change during film formation or aging. This is important, since these coatings do not rely on temperature, humidity, solar radiation, or moisture vapor in order to cure in place.

As long as the solvents evaporate from the film, the finished coating can form with all of the properties inherent in the basic resin. While these factors are benefits, as a thermoplastic material, the film has inherent limits on temperature resistance and resistance to organic solvents.

4.3.1.2 Chemical and Water Resistance

A vinyl coating is basically inert to almost all inorganic substances (e.g., acids, alkalis, and salts), as well as to water, oil, grease, alcohols, and similar materials. There are only a few materials, its own solvents or similar products, which will destroy its film integrity. Vinyl coatings also are generally unaffected by continuous water exposure. These properties factor into vinyl's use as a long-term-extended use coating.

4.3.2 Variations of Vinyl Resin

The following are common variations on the basic vinyl resin which are of interest to the corrosion industry.

4.3.2.1 Vinyl Organosols and Plastisols

Vinyl chloride polymers of high molecular weight may also be applied as organosols and plastisols. These coatings, based on very high molecular weight resins of vinyl chloride (produced by emulsion polymerization followed by spray drying) with or without co-monomers, are applied as fine particles of polymer dispersed in volatile non-solvents (organosols) or in plasticizers (plastisols) and applied as dispersions. After application (by spraying, dip coating, reverse roll coating, knife coating, etc.), the coatings are baked at a high enough temperature to fuse the individual particles of resin together.

Vinyl dispersion resins are widely used in fabric coatings, synthetic leathers, floor coverings, overshoes, gloves, wire goods, tool handles, racks, and other application.

4.3.2.2 Vinyl Powder Coatings

Zero VOC vinyls are possible with powder coating technology, in which somewhat similar resins are used as binders for coatings. In this case, the liquid continuous phase is essentially replaced by air. The coatings are applied either with electrostatic spray followed by fusing, or with a fluidized bed process in which the heated articles to be coated are passed through a field of powder suspended in air, which melts onto the articles which are then baked to final cure.

Vinyl powder coatings are largely used for metal furniture and cabinets, gas distribution pipelines, tools, electric motors and transformers, bottles, racks, and small metal parts of all kinds.

4.4 Asphaltic Coatings

4.4.1 Asphalts

Asphalt is a naturally occurring bituminous material, derived either by mining gilsonite (a naturally occurring asphalt) or comes from the residue of distilling asphaltic petroleum. Gilsonite is a solid material mined similarly to coal. It is soluble in aliphatic and aromatic solvents and has excellent chemical resistance and good weather resistance. Asphalts vary in their chemical and physical characteristics, depending on the distillation process and temperatures to which they are subjected. They also may be subject to steam distillation and to air blowing during the distillation process. The chemical makeup of asphalt is not complex. The various types of asphalt are primarily based on different melting point- or softening point materials.

Chemically, asphalt is a stable aliphatic hydrocarbon, which has good resistance to water and most chemicals and salts. It is solvent sensitive, even to aliphatic solvents, and is softened and dissolved by vegetable oils. When exposed to weather the coatings tend to lose gloss and chalk, but they maintain their chemical resistance and are not prone to alligatoring.

Asphalts are often combined with solvents in order to form a thermoplastic, lacquer-type film. Hard asphalt is dissolved in solvents in what is called an asphalt "cut back." Asphaltic coatings can also be combined with higher-molecular-weight-polymer petroleum resins, which increase the strength and provide more flexibility than asphalt used alone. These are still thermoplastic materials and are usually referred to as "polymer modified." Asphaltic coatings are also made with inert fillers, which add to the thickness of the coating and, in many cases, to its impervious characteristics. Asphalt can also be applied as a 100% solids coating via a "hot-melt" process.

Many water tanks are coated with asphalt because of its nontoxic and relatively tasteless nature. Asphalt generally has good corrosion-resistant properties and it may be used wherever a decorative coating is not required. While some asphalt coatings are heavily pigmented, it is primarily a black coating, and this characteristic is difficult to change. It may be applied effectively over other coatings that have sound substrate adhesion, although it is a very difficult material to overcoat because of its sensitivity to oils and solvents of all types.

4.4.2 Coal Tar

Coal tar coatings are similar to asphaltic coatings. Coal tars are derived from a by-product that comes from the coal coking process. This by-product is further distilled to produce coal tar pitch.

Coal tar coatings are made by dissolving processed coal tar pitch in suitable solvents. They dry entirely by evaporation of solvents (i.e., thermoplastic). Their properties depend to a great extent on the type of coal tar raw materials and their blending. The outstanding properties of coal tar coatings that contribute to their corrosion resistance are:

- Extremely low permeability to moisture
- High dielectric resistance

Coal tar coatings generally are not affected by mineral oil, but can be dissolved by vegetable or animal oil, grease, and detergents. They have good resistance to weak acids, alkalis, salts, seawater, and other aggressive atmospheres. Their corrosion resistant properties come from their impermeable film — they exclude moisture and air from the underlying surface. They are alkali resistant and can be applied to concrete as well as steel.

Coal tar coatings have a tendency to alligator in direct sunlight. This happens when the top of the coal tar film hardens from the sun's ultraviolet rays. The top of the film contracts and slips over the softer layer causing alligator marks.

The major differences between coal tar and asphalt are the excellent water resistance of coal tar and the good weather resistance of asphalt. The asphaltic materials are used more for above ground uses, while coal tar coatings are used underground.

4.5 Acrylic Resins

Acrylic resins are primarily polymeric derivatives of acrylic and methacrylic acid. More important resins are polymers of methyl and ethyl esters of these acids or copolymers of mixtures of these monomers. Propyl, butyl, and isobutyl esters are also used, as well as acrylamides, acrylonitriles, and other similar materials. These monomers can be blended in many proportions, then polymerized into finished resins.

Because of esterfication variations and the copolymerization of the esterified acrylic monomers, there are a tremendous number of possible combinations. The polymers vary from very hard, brittle materials to very soft, flexible plastics.

Acrylics resins are primarily used as product finishes on automobiles, refrigerators, and such, which need a long-lasting factor-applied finish.

The solution and film properties of acrylic polymer coatings are regulated by the molecular weight, the nature of the polymer solution, and the composition of the polymer or copolymer chemical structure. Up to application limits, increased molecular weight benefits corrosion performance.

Acrylic resins are known for their water-white color and resistance to color change over time. They generally have excellent durability and are not so susceptible to chemical change.

Traditional acrylic resins are non-convertible. A common example is an unpigmented acrylic resin used as a clear coat on automobiles. Similar acrylic lacquers exist for other OEM equipment applications.

Convertible acrylic materials also exist. The acrylic is added to these resins to increase their exterior durability and weather resistance, and to retain appearance over long periods of time. Such modified acrylic materials have excellent color, gloss, and weatherability.

There is an important category of latex (or water based) acrylic paints. These mix suitable acrylic monomers in a water base that once dried and coalesced, form a cohesive film on a metal surface. They typically weather extremely well, and when combined with suitable corrosion inhibitors, provide excellent long-term corrosion resistance on steel substrates. Because they are water-based materials, they usually require better surface preparation than conventional solvent-based systems.

Chapter 6: Testing Coating Properties and Performance

OBJECTIVES

Upon completion of this chapter, you will be able to:

OBJ 6.1: Identify various types of tests that can be performed on coatings

6.1 Sources for Coating Test Procedures

There are a wide range of tests used to evaluate protective coatings and linings; literally thousands of test methods exist for protective coatings and linings. Test methods are produced by various trade associations, government entities, product manufacturers and infrastructure owners. Fortunately, many of the tests are simply variations on a theme. ASTM International[1] publishes many test methods. ASTM Section 06: "Paints, Related Coatings, And Aromatics" contains over 800 test methods in 4 volumes:

- Volume 06.01 Paint — Tests for Chemical, Physical, and Optical Properties; Appearance
- Volume 06.02 Paint — Products and Applications; Protective Coatings; Pipeline Coatings
- Volume 06.03 Paint — Pigments, Drying Oils, Polymers, Resins, Naval Stores, Cellulosic Esters, and Ink Vehicles
- Volume 06.04 Paint — Solvents; Aromatic Hydrocarbons

ASTM methods are generally accepted throughout the world. The ASTM Committee D01, formed in 1902, meets twice a year and has more than 500 members. This committee has jurisdiction of over 670 standards, published in the annual Book of ASTM Standards, Volumes 6.01, 6.02, 6.03, and 6.04. These standards address classification, sampling, preparation, components, application, analysis, quality assurance, and end-use performance requirements.

ASTM D6577-00, Standard Guide for Testing Industrial Protective Coatings, details the selection and use of test methods and procedures for industrial protective coatings.

ISO (International Organization for Standardization) also produces a series of standard test methods for coatings, many of which are similar to ASTM standards. The following five ISO technical subcommittees work closely with ASTM D01:

- TC 35/SC 2 Pigments and extenders
- TC 35/SC 9 General test methods for paints and varnishes
- TC 35/SC 10 Test methods for binders for paints and varnishes
- TC 35/SC 12 Preparation of steel substrates before application of paints and related products
- TC 35/SC 14 Protective paint systems for steel structures

In addition to these standards organizations, many trade associations (including NACE) publish coatings standards which are tailored to the industry they serve.

1. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, 19428-2959 USA http://www.astm.org

While the test methods published by the various organizations in many cases appear to be similar, it is important to recognize that there are often subtle differences which exist in the procedures. While many of these differences are trivial, **sometimes these differences can make a significant difference in the interpretation or comparison of test results**. Before comparing data from different sources, it is important to know what test procedures were followed.

6.2 Coating Test Procedures

Why Test Coatings?

There are several reasons it is important to test coatings. It is helpful in order to predict performance and determine the suitability in unique environments or critical performance areas. It validates manufacturers' claims and holds the manufacturer accountable. Testing serves as a basis for selecting and specifying materials, provides quality assurance of individual coating batches, and offers an understanding of formulation or process effects. It also leads to failure analysis.

Why Have Standard Test Methods?

Standard test methods are necessary in reducing test costs and improving precisions of test results. No standards can lead to ambiguous test results. By standardizing test methods, a foundation for quality management is put in place. This provides specifications and world-wide bid documents to reduce costs and ensure fair open competition.

6.2.1 Test Classifications

This section will discuss general principles of various test methods and their usefulness in evaluating coating materials. The reader is referred to actual test methods for specific details.

Test methods can be broadly grouped into the categories of **Physical Properties Tests** and **Performance Tests**.

- **Physical properties** tests are generally performed to quantify some aspect of the coating at a given point in time (i.e., before application, after application, or after some period of service).
- **Performance** tests are generally performed to determine if a coating is suitable for a given service and/or to develop some estimate of service life.
- Testing may be done in the field or in the laboratory and many physical properties and performance test may be done in both.
- Field testing is more realistic; however, the conditions are uncontrolled.
- Laboratory testing is more controlled; however, the results may not be realistic
- There are thousands of tests, with many variations of basics tests, that may be completed by the manufacturer, independent labs, and purchasers. It's important to know what procedure to follow. This can be done by obtaining and referencing test methods. Often, within a given test, multiple actions may be used to perform an individual test procedure; therefore, the tester should be aware that using different methods may impact test results.
- Tests should be selected that are appropriate for its intended use. Testers should understand what tests are comparable and which aren't as well as understand the intended purpose of each test procedure.

6.2.2 Test Considerations

- The following should always be considered during any coating test procedure:

- **Replication:** All tests should be reported. Some standards exist that require multiple testing and results from various sources may be considered.
- **Complete reporting requirements:** When reporting test outcomes, ensure all results are reported and identify whether the test method used was modified in any way.
- **Chain of custody:** It's important to note where the test sample came from and ensure it is not altered in any way.
- **Manufacturer test data:** When manufacturers perform tests, it is typically done in a laboratory; the results may not represent the field environment.
- **Applicability of tests:** For tests to be fully applicable, they should relate to the material and environment and incorporate actual field conditions when appropriate, e.g., curing conditions.
- **For a coating film, cure conditions may impact performance**: A forced cure or curing using actual cure conditions will make a difference.

Test results will vary somewhat but it's important to ensure precision and accuracy. Test results obtained under prescribed conditions should closely agree with similar tests results. Variability can be expected between test results when the test method is used by one or more certified laboratories. Always try to replicate, repeat, and reproduce to verify test results and be aware of bias that may contribute to a difference between the mean of a large number of test results and an accepted reference value.

6.2.3 Representative Sections in a Standard Test Method

Different test methods contain similar sections, though the wording may be a little different. Most test methods have a statement about accuracy. This allows the user to determine if differences are indicative of true differences or the result of variation of test procedure. Most test methods have a list of items to include in a report. Multiple tests are sometimes required by the standard. The report may also require identification of the specific method variations used or other clarifying information required for proper interpretation of the test results. Ancillary information in the test method is not "required," but should be reviewed for relevance to your particular circumstance.

Notice the difference between the ASTM Test Method and ISO formats below:

ASTM Test Method Format:

- Scope
- Reference Documents
- Summary of Test Method
- Interferences
- Significance and Use
- Apparatus & Reagents
- Test Specimens
- Procedure
- Data Evaluation/Calculations
- Report
- Precision and Bias
- Appendices

ISO Format:

- Scope
- Normative References
- Definitions
- Principle
- Reagents
- Test Samples
- Apparatus and Materials
- Procedure
- Expression of Results
- Accuracy
- Test Report
- Annexes

6.3 Physical Properties

Tests for physical properties of coatings evaluate particular properties of the coating. It is important to understand that, to varying degrees, these properties can change over time. With that in mind, physical properties tests might be conducted on new coatings to validate that they have the desired/intended properties or they may be performed on aged coatings to determine the extent to which the properties under question have changed.

To facilitate the reader, the physical properties tests will be further sub-classified into:

- Liquid coatings properties
- Application and film formation
- Properties of the dried film

6.3.1 Liquid Coating Properties

Tests for liquid properties of coatings are performed on the material before it changes from a liquid to a solid state. In the case of two-component systems, some tests are performed on the individual components while others are performed on the mixed material. Note that most properties of the mixed two-component coatings will vary as they react. For example, coating viscosity increases with time, especially near the end of the pot life.

Liquid coating properties tests may be used for QA/QC during production, for lot acceptance at the purchaser’s location, or as part of a process to recertify batches which have exceeded their shelf life.

6.3.1.1 Condition in Container

Requirements for the coating’s condition in container may be spelled out in contract documents or a referenced requirement. For liquid coatings, this typically requires that the coating be free of objectionable characteristics such as skinning, curdling, agglomeration of pigment, gelling, seeding, and putrefaction. Thickening, settling and separation are undesirable and objectionable unless the coating can be reconstituted with a reasonable amount of stirring.

Settling: Pigments and fillers dispersed in paints are subject to some settling. However, excessive settling may prevent the paint from being re-homogenized in a reasonable time using conventional mixing tools. ASTM D 869, "Standard Test Method for Evaluating Degree of Settling of Paint," describes a procedure for determining the degree of pigment suspension and ease of remixing a shelf-aged sample of paint. The test requires that a paint sample be stored in a 500-mL (1 pt) container for 6 months. After storage, the extent and character of settled portions is evaluated. The ability to remix the coating is also subjectively evaluated.

Odor: Odor is associated with the volatile components of a coating. ASTM D 1296, "Standard Test Method for Odor of Volatile Solvents and Diluents," describes a comparative procedure for observing the characteristic and residual odors of solvents and diluents. The test method was not specifically designed for coatings but may be used as a basis for comparing odors.

Package stability: Liquid coatings must be relatively stable in their packaging so that they perform acceptably when they are used. ASTM D 1849, "Standard Test Method for Package Stability of Paint," evaluates the changes in consistency and certain other properties that may take place when liquid paint (solvent- or water-reducible) is stored at temperatures above 32°F (0°C). The standard suggests accelerating the storage time for a coating sample by increasing the temperature to 125°F (52°C), but notes that this may not accelerate all changes. After the test period, the liquid coating is examined for settling, consistency, and the development of grains or lumps.

6.3.1.2 Freeze-Thaw Stability

Waterborne coatings must be able to withstand the effects of freezing during shipping and storage. Suitable stabilized products can withstand several freeze-thaw cycles without viscosity increase, coagulation, or other physical changes. ASTM D 2243, "Standard Test Method for Freeze-Thaw Resistance of Water-Borne Coatings," describes a test method for evaluating the effect of freeze-thaw cycling on the viscosity and visual film properties of water-borne coatings. The method involves comparing the properties of two 500-mL (1 pt) containers of coating wherein one has undergone five or more cycles between 0°F (-18°C) and room temperature. After testing, both the test and referee samples are evaluated for condition in container, consistency/viscosity, and film properties.

6.3.1.3 Microorganism Resistance

ASTM D 2574, "Test Method for Resistance of Emulsion Paints in the Container to Attack by Microorganisms," can be used to determine if a liquid coating contains live bacteria and if it can resist attack by bacteria. Bacteria can cause putrefaction or fermentation of waterborne paints.

6.3.1.4 Fineness of Dispersion

Generally, the more finely a pigment is dispersed in the liquid vehicle, the more efficiently it is being utilized. The fineness of dispersion or fineness of grind is a measure of the degree to which pigment has been broken down into fine particles. ASTM D 1210, "Test Method for Fineness of Dispersion of Pigment-Vehicle Systems by Hegman-Type Gage," is used to make this measurement. The method requires a precision machined tool — either a tapered path or a stepped gauge. With the tapered gauge, the product is spread in a machined, tapered path. At some point, pigment particles will form a definite pattern — this is determined to be the fineness of grind.

The stepped gauge has two sections of different machined depth (typically 1 mil and 3 mils). The paint is drawn into the areas with a scraper and the number of visible particles in counted. A formula is used to determine cleanliness (texture).

6.3.1.5 Coarse Particles and Foreign Matter

Coarse particles and foreign matter in liquid coatings can adversely affect appearance of the dried film and may clog lines, filters, and tips of spray equipment.

ASTM D 185, “Test Methods for Coarse Particles in Pigments, Pastes and Paints,” defines material retained in a 325-mesh (45 µm) screen as unacceptable. Typically, a maximum of 0.5% by weight of coarse particles and foreign matter is allowed.

6.3.1.6 Density (Weight per Gallon)

The density of a paint as measured by weight per gallon (or weight per liter) can be used as an indicator of product uniformity. If different materials or different proportions are used, the density of the liquid coating will change.

Density is commonly recorded during manufacture as a QA/QC parameter and may also be used as a lot acceptance test by the purchaser. ASTM D 1475, “Test Method for Density of Liquid Coatings, Inks, and Related Products,” describes a method for measuring the density of liquid coatings. The procedure involves filling a calibrated cup with the liquid coating. The cup is weighed when full and again after removing the coating. A simple calculation converts the weight of a known volume to density.

6.3.1.7 Viscosity

Viscosity refers to the flow resistance of a fluid. Viscosity can impact application characteristics such as flow, leveling, and sag resistance. The viscosity of some coatings (and other Non-Newtonian liquids) is dependent on the shear rate (a measure of the force applied). Most coatings are designed with a certain degree of thixotropy. Thixotropic materials are gel-like at rest, but become fluid when subject to shear forces like agitation, a brush stroke, or air pressure. Thixotropy is what allows coatings to be applied easily but also cling to a vertical surface at an adequate film thickness before drying.

There are several methods for measuring viscosity. In the laboratory, sophisticated instruments may be used to determine viscosity at multiple shear rates, allowing a plot of the coating behavior to be generated. A less sophisticated technique is described in ASTM D 562, “Test Method for Consistency of Paints Using a Stormer Viscometer.” This method involves determining the force required to produce a specific rate of rotation of a specific sized paddle immersed in the liquid coating.

Viscosity cups are used to measure viscosity of coatings in the field. Viscosity cups are precisely machined cups with a hole in the bottom. The cup is dipped into the mixed paint and the number of seconds for the paint to drain from the cup is measured. ASTM D 1200, “Standard Test Measurement for Viscosity by Ford Viscosity Cup,” and ASTM D4212, “Standard Test Measurement for Viscosity by Dip-Type Viscosity Cups” de-scribe different viscosity cups. These methods are useful for determining proper levels of thinning or for field confirmation of coating viscosity.

6.3.1.8 Flash Point

The flash point is the lowest temperature at which a vapor will ignite if presented with an ignition source (e.g., flame or spark). There are many methods to determine flash point. One method involves controlled heating of a small sample of coating in a closed apparatus, exposing the vapor to a flame and observing for ignition. Iterative testing is required to determine the flash point. Flash point is provided on Product Data Sheets and Material Safety Data Sheets.

6.3.1.9 Volatile Content/ Volatile Organic Compound Content

The volatile content of paint and coatings is useful for producers and users in a variety of ways. The most obvious use relates to understanding environmental, health and safety impacts of the product. But the data is also useful when calculating coverage rates, determining thinning ratios (if appropriate), and selecting application methods. There are numerous ways to determine volatile content of paints and coatings. ASTM D 2832, “Standard Guide for Determining Volatile and Nonvolatile Content of Paint and Related Coatings,” describes which of the ASTM test methods should be applied to various coatings.

Determination of volatile organic compound (VOC) content is often performed to comply with specific laws and regulations. As regulations and laws evolve, some solvents are being classified as "exempt," meaning that they do not count to that particular agency's definition of VOC. This makes it critical for users of data to identify which test methods are used to generate reported data. It is also an explanation for what may be perceived as an inconsistency between reported VOC and volatile content.

The simplest methods for determining volatile content of coatings are based on weight difference between wet and cured film. More sophisticated methods allow speciation of volatile content by analyzing headspace vapor above a curing coating using an analytical technique such as gas chromatography.

6.3.1.10 6.3.1.10Volume Solids Content

The volume solids content of a coating is the portion of the liquid material which will remain as a dried film on the surface, assuming 100% transfer efficiency. This characteristic can be used to determine the volume of liquid coating which will be required to cover a given square footage of surface assuming some practical transfer efficiency.

For various reasons, the practical volume solids content **does not** equate to that which could be determined by simple addition of the weights and volumes of the raw materials in the formulation. One reason is that the volume of a resin/solvent solution will not equal the sum of the individual volumes. A second reason relates to the spatial configuration of the pigments. As the coating approaches and exceeds critical pigment volume concentration (i.e., the point at which there is just sufficient polymer to wet the pigment particles), the apparent volume of the dried film becomes greater than the theoretical value.

Volume solids content essentially requires determining the volume of a dried film and comparing it to the volume of liquid coating required to apply the film.

6.3.1.11 Chemical Analysis

Chemical analysis determines the presence of specific components and their quantities. The analytical chemistry methods used to analyze a coating are very complicated. They often require two steps: one procedure to isolate the chemical or component of interest, and a second step to quantify the amount of the chemical. In many cases, only relative amounts of the chemical can be determined, not actual quantities.

Chemical analysis can be performed on liquid and dried samples. Obviously, it is not possible to quantitatively identify volatile material from a solid (dried) sample. Analytical chemistry may be used to determine liquid coating composition (e.g., for QA/QC or lot acceptance), identify specific constituents which should (or should not) be present in the coating, and to perform forensic analysis of coating failures.

The analytical techniques used to analyze coatings include infrared spectroscopy, gas chromatography/mass spectrometry (GC/MS), inductively coupled plasma-atomic emission spectroscopy (ICP-AES), and many others.

6.4 Application and Film Formation

Tests for application and film formation evaluate the ability of a liquid coating to be applied using specific equipment to a given substrate. These tests may be performed to evaluate the ability of the film to be applied, help understand the dynamics of drying and curing, qualify material for use and for acceptance testing.

6.4.1 Transfer Efficiency

The transfer efficiency of a coating is a ratio of solids deposited to solids used during application, expressed as a percent. Transfer efficiency is dependent on the application method, application equipment, operator skill, objects being coated, and the environmental conditions. Because of the

many conditions which impact transfer efficiency, values derived from testing should be used as a guide only.

Various test methods are available to determine transfer efficiency. The methods generally describe a set of controlled conditions in which paint is applied to a target object. The volume or weight of the coating deposited is then measured and compared to the volume of weight of the coating used.

Transfer efficiency data may be useful to estimate the actual quantity of material needed on a job. The data is also useful when selecting equipment. Some regulations exist which require coatings to be applied with equipment that can achieve target transfer efficiency.

6.4.2 Application Properties

Application properties refer to the ease with which a liquid coating can be applied using given equipment. There are various test methods available which describe the process of applying a coating with the equipment of interest in a controlled fashion and list properties which should be observed during application. In some cases, actual tests of the film properties may be required (e.g., gloss, color, thickness, etc). Generally the application properties of the test coating are compared to a standard. The standard may be the same coating applied with known acceptable equipment or a reference coating applied with the same equipment as the test coating.

6.4.3 Drying Properties

Drying time is an important characteristic for coatings. The length of time for a coating to dry dictates how long one must wait until the coating can be handled or recoated. ASTM D1640, "Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature," is one of the methods which describes dry time tests. The procedure involves applying a prescribed thickness of coating. The degree of dryness is determined in accordance with standard definitions:

- **Set-To-Touch Time**: The film is set-to-touch when it still shows a tacky condition, but none of it adheres to a finger lightly touched on the film.
- **Dust-Free Time**: The film is considered to have dried dust free when cotton fibers dropped onto the film can be removed by blowing lightly over the surface of the film.
- **Tack-Free Time**: This is determined using a "Tack Tester" machine. The standard tack tester is fully described in the U.S. Patent 2,406,989, Sept. 3, 1946.
- **Dry-To-Touch Time**: The film is considered dry when it no longer adheres to a finger and does not rub up appreciably when the finger is lightly rubbed across the surface.
- **Dry-Hard Time:** The operator exerts a maximum downward pressure (without twisting) of the thumb on the film and lightly polishes the contacted area with a soft cloth. The film is considered dry-hard when any mark left by the thumb is completely removed by the polishing.
- **Dry-Through (or Dry-To-Handle) Time**: The film is considered dry-through or dry-to-handle when there is no loosening, detachment, wrinkling, or other evidence of distortion of the film after bearing down on the film with the thumb, exerting the maximum pressure of the arm, at the same time turning the thumb through an angle of 90° in the plane of the film.
- **Dry-To-Recoat**: A film is considered dry for recoating when a second coat or specified topcoat can be applied without the development of any film irregularities such as lifting or loss of adhesion of the first coat, and the dry time of the second coat does not exceed the maximum specified (if any) for the first coat.

6.4.4 Leveling Properties

Leveling is an important property when uniform surfaces are to be produced. Uniform surfaces might be required for aesthetics (e.g., uniform appearance). Uniform surfaces are also helpful to ensure materials are not entrapped on the surface (e.g., when tanks are drained or to allow water and debris to properly run off a surface). ASTM D 4062, "Standard Test Method for Leveling of Paints by Draw-Down Method," describes the laboratory determination of the relative leveling of water and solvent-reducible architectural paints in light tints. The test method involves applying a coating film to a special card using a special draw down apparatus. The draw down apparatus creates a film with parallel ridges simulating brush marks. After drying, the degree to which the ridges level or become smooth is rated by comparison with a series of plastic leveling standards.

6.4.5 Low Temperature Coalescence

As temperatures decrease, latex particles in a coating may not coalesce as effectively. ASTM D 3258, "Standard Test Method for Porosity of White or Near White Paint Films by Staining," describes a method to compare coalescence of latex paints by determining the porosity of films dried at standard and at low temperature.

6.4.6 Wet Film Thickness (WFT)

Wet film thickness measurements allow the applicator to check the thickness of the coating during the application process. This provides the applicator with immediate feedback on the thickness being applied and allows for adjustments in application technique in real-time.

The WFT gauge consists of two end points on the same plane, with progressively deeper notched steps in between. Each step is given a number representing the distance in mils (or µm) between the step and the plane created by the two end points. The instrument is pressed firmly into the wet film, down to the surface, and withdrawn. The two end points will be wetted by the coating material and maybe some of the steps in between. It is important that the gauge not be dragged across the surface.

The WFT is considered to be the last wet step observed. If no steps are wet, the gauge needs to be turned to a different side, which can measure WFT of that particular coating.

WFT readings should be taken as soon as possible after coating application. As soon as coatings leave the container, evaporation begins; and the percentage of solids by volume changes slightly.

Wet film thickness of some coatings cannot be accurately measured. This occurs with coatings which cure quickly (e.g., polyurea, inorganic zincs) and coatings containing pigment which interferes with the measurement (e.g., inorganic zinc, non-skid coatings).

Care must be taken that the instrument is not used on any surface irregularities that might distort the measurements. On curved surfaces, readings should be made along the length of the curve, rather than across its width, to prevent irregular wetting of the steps.

6.4.7 Touch-up

Most applied coating systems are subject to some level of damage during subsequent production, delivery, installation, or use of the coated component. For aesthetic or functional purposes, it may be desirable to touch-up the coating by applying coating to the damaged area using a bristle brush, sponge brush, or air brush. Key issues with touch-up are the ability of the touch-up coating to match the appearance of the original coating and the adhesion of the touch-up coat to the original coat. This can be tested by applying a touch-up coat to a previously coated panel and inspecting for appearance differences and adhesion using appropriate test methods (e.g., test methods for color, gloss, texture, adhesion, etc).

6.4.8 Sag Resistance

Sag resistance is described as the ability of a coating to maintain thickness in a liquid state under the force of gravitational stress. Obviously, coatings cannot be applied to vertical surfaces at wet film thicknesses above their sag resistance. It is desirable to have a sag resistance significantly higher than the target wet film thickness. On the other hand, coatings with very high sag resistances may be applied too thickly and have weaknesses such as porosity and solvent entrapment that are associated with thick coatings. Whether or not a coating sags is related to the wet film thickness, density, and viscosity of the coating.

ASTM D4400, "Test Method for Sag Resistance of Paints Using a Multinotch Applicator," is one method to determine the sag resistance of a coating. The test involves applying parallel lines of a coating film at varying thicknesses to a cardboard substrate. The card is held vertically while paint dries. The thickness of paint which does not sag a defined distance is called the sag resistance of the coating.

6.4.9 Pot Life

Pot life is defined by NACE as *"the elapsed time within which a coating can be effectively applied after all components of the coating have been thoroughly mixed."* Pot life is a critical issue when applying catalyzed coatings. It is important to note that some coatings which have exceeded their pot life may appear to be effectively applied but may not cure properly (e.g., not have adequate adhesion or have poor appearance due to insufficient leveling).

Pot life can be determined by monitoring the change in liquid coating properties over time subsequent to mixing the coating. This may include monitoring viscosity with time or applying the coating to substrates and determining any of a variety of application properties or performance characteristics (e.g., sag resistance, leveling, adhesion, gloss).

6.5 Properties of Dried Film

These are tests of the physical properties of an applied coating. They may be performed on newly applied coatings or aged coatings. Coatings undergo physical changes as they age, so test results from aged coatings must be carefully interpreted.

On new coatings these tests may be used as a basis to accept the contractors work or as a basis to compare aged coatings. On aged coatings these tests may be performed as part of forensic analysis, to determine maintenance needs, or to project service life.

6.5.1 Color

Color measurement can be a very sophisticated and somewhat complicated science. Instruments called colorimeters are available to precisely measure color. These instruments are used by many trade sales paint stores to custom blend colors which will match existing paint chips or objects. In contrast, simple comparator chips have been used by the coatings industry for years to specify the color of paint.

Color may be specified or measured independently or as a color-difference with respect to some standard. To evaluate the color of a liquid paint, a film is typically applied to a black and white contrasting color card using conventional means. The film should be sufficiently opaque to obscure the contrasting colors of the card.

Visual evaluation for color difference is fast and acceptable for most comparative purposes. If determining color difference by visual evaluation, the investigator should be sure to use adequate illumination, sample sizes and viewing conditions. Suitable conditions are described in ASTM D 1729, "Practice for Visual Appraisal of Colors and Color Differences of Diffusively-Illuminated Opaque Materials," and ASTM D 2616, "Test Method for Evaluation of Visual Color Differences with a Gray Scale."

Instrument determination of color is a complicated matter which is commonly referred to as colorimetry. With respect to coatings, colorimetry involves reducing the light spectra reflected from the measured surface to tristimulus values, from which the perception of color derives. To eliminate some of the complexities of color measurement, standard criteria were agreed upon at the 1931CIE (Commissione Internationale de L'Eclairage) conference. This has resulted in what are referred to as the CIE tristimulus values — the X, Y, Z color coordinate system. This system allows color to be described mathematically in a three-dimensional space where the X-axis represents red, the Y-axis represents green and the Z axis represents blue-violet. Any color can be described as a combination of these three. Other common color coordinate systems (such as the L, a, b system) can be mathematically derived from the standard CIE system. Color differences can be mathematically calculated in this space as well. The calculation of color difference (referred to as ΔE) is simply the length of the vector between two points in the color space.

6.5.2 Gloss

Gloss is the capacity of a surface to reflect more light in some directions than in others. The directions associated with mirror (or specular) reflection are measured with gloss measurement equipment. Measured gloss ratings are obtained by comparing the specular reflectance from the test sample to that from a black glass standard. Gloss readings are made with light at an incident angle of 20, 60, or 85 degrees to allow for greater differentiation of flat and glossy surfaces. Measurements at 85 degrees are appropriate for flat surfaces.

6.5.3 Hiding Power

Hiding power is a measure of the ability of a coating to hide the surface. Hiding power can be measured according to ASTM D 344, "Test Method for Relative Hiding Power of Paints by the Visual Evaluation of Brushouts." The test method describes a practical approach in which a representative film is applied to a black and white card. Based on comparison of two or more coatings, their relative ability to hide the contrasting colors can be determined. Alternatively, the thickness at which a given coating effectively "hides" the surface can be determined by performing the test on a given coating applied at multiple thicknesses. ASTM D 2805, "Test Method for Hiding Power of Paints by Reflectometry," describes an instrumental method for determining hiding power based on reflectometry.

6.5.4 Abrasion Resistance

There are a variety of test methods to evaluate the ability of dried coatings to withstand wearing by relative movement of another solid, liquid, or gas. Test methods have been developed which subject the dried film to air propelled abrasive, falling sand, impinging fluids, or abrasive surfaces.

A commonly reported test value is based on ASTM D 4060, "Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser." The test apparatus abrades a coating applied to a flat panel by rotating the panel under weighted abrasive wheels. Abrasion resistance is calculated as loss in weight at a specified number of abrasion cycles, as loss in weight per cycle, or as number of cycles required to remove a unit amount of coating thickness.

6.5.5 Adhesion

Adhesion is the coatings ability to resist removal from the substrate. There are a number of test methods designed to evaluate the adhesion of a coating. It is important to consider the adhesion test compared to potential adhesive failure modes. Adhesion tests have been described which subject the coating to scraping forces, tensile forces, probing with a knife, and peeling forces.

6.5.6 Dry Film Thickness (DFT)

Coating DFT can be measured with a variety of instruments including **non-destructive** and **destructive** gauges.

6.5.6.1 Non-Destructive Testing

Non-destructive gauges include magnetic and ultrasonic gauges. Non-destructive gauges may be used to measure the thickness of a newly applied coating for QA/QC. ASTM D 7091, "Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals," and SSPC-PA 2, "SSPC Paint Application Standards, Guides and Specifications," define similar methods for calibrating magnetic-type DFT gauges and for taking DFT measurements of nonmagnetic coatings over a ferrous magnetic metal surface.

There are two types of **magnetic gauges**: **Type 1** and **Type 2**.

Type 1, also called **pull-off gauges**, measure the force required to pull a permanent magnet from a coated ferrous metal surface. These gauges can be dial- or pencil-type. **Type-2** gauges are also referred to as **fixed probe gauges**. These electronic gauges employ measuring probes which work on the magnetic induction, Hall-effect or eddy current measurement principle. A variety of Type-2 gauges are manufactured with various electronic data collection features.

Magnetic DFT gauges have various limitations which need to be considered during their use including:

- Different calibration standards used with different magnetic gauges
- Unclean magnets alter results
- Soft coatings cause thin readings
- Vibrations can cause high readings
- Some Type-1 gauges have dials which continue to turn when the magnet lifts off the surface, giving an incorrect reading
- Type-2 gauges require special probes for measuring on curved surfaces, inside angles, or in the presence of stray magnetic fields

Eddy current instruments are used to test the DFT of non-magnetic films applied to ferrous and nonferrous metals, concrete and other non-metallic surfaces. Instrument readings can be influenced by magnetic and conductive properties of the substrate, substrate thickness, edges, curves, and the conductivity of the coating.

6.5.6.2 Destructive Testing

Destructive tests for coating thickness have the advantage of allowing measurement of individual layers of a coating system (if they are of contrasting color). One such destructive gage is a **Tooke Gauge**. The test involves microscopic observation of a precision angular cut in a coating film. Tooke Gauges are the most commonly used of the three methods covered in ASTM D4138-07a, "Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means."

6.5.7 Elongation

Elongation tests measure the ability of a coating to withstand an increase in length. These tests are an indication of coating flexibility. ASTM D 522, "Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings," is a common test which indicates ability of a coating to withstand deformation without cracking. The test involves applying a coating to a test panel which is subsequently bent around a mandrel. The coating is inspected for cracking around the bent area. The test can be performed as an acceptance test if a specific bend diameter is defined. Instruments also exist which have a conical mandrel around which the panel is bent, which determines the specific elongation the coating can withstand.

6.5.8 Internal Stresses

Internal stresses arise in a coating as the result of various phenomena including shrinkage during cure, expansion when a coating adsorbs liquid, and differences in thermal expansion coefficients of coating and substrate. These internal stresses can cause a coating to crack or lose adhesion. There are complicated test procedures which can be used to determine exactly how much internal stress is induced in a coating under various scenarios. If a coating is applied to one side of a thin metal foil, the composite foil/coating will tend to bend when the coating shrinks during cure and shrinks or expands due to exposure.

6.5.9 Hardness

Hardness is the ability of dried a coating to resist indentation. There are several methods to measure hardness of a coating. ASTM D3363-05, "Standard Test Method for Film Hardness by Pencil Test" describes procedures where a selection of pencils of varying degrees of hardness is used to determine coating hardness. Factors affecting test accuracy include lead grade hardness, the amount of pressure applied, and interpretation of the indentation.

Several hand-held hardness testers are available for use in the field. Generally these involve making an indentation in the coating and observing either the force required to penetrate the film or the degree of indentation under prescribed conditions. Coating hardness readings may be influenced by material type, cure, ambient temperature, material thickness, and size of the test piece. The use of a popular hardness tester is covered by ASTM D2583-07, "Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor."

6.5.10 Discontinuities (Holidays)

A coating holiday is a discontinuity in a protective coating that exposes the unprotected surface to the environment. Voids, cracks, thin spots, and foreign inclusions can result in these holidays which compromise coating performance. Frequently, coating holidays are minute and not readily visible. ASTM D5162, "Standard Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates," and NACE TM 0186, "Holiday Detection of Internal Tubular Coatings of 250 to 760 µm (10 to 30 mils)," describe test methods which employ an electrical current to detect film defects.

Holiday tests are typically employed on critical applications such as buried pipelines or tank linings.

6.5.11 Impact Resistance

Impact resistance refers to the ability of a dried coating to resist a striking blow or impingement. There are various methods to determine impact resistance using a falling weight. The falling weight imparts a defined amount of energy on the coated surface. The coating is inspected for cracking after the test.

6.5.12 Burning Characteristics

ASTM E 84, "Test Method for Surface Burning Characteristics of Building Materials," describes a procedure for determining the rate of response and extent of degradation when coatings are exposed to fire.

6.5.13 Slip Coefficient and Creep Resistance

Coatings are often applied to steel surfaces before they are bolted together. Because the coatings become part of the bolted joint, they must not have any adverse effect on the ability of the joint to attain the required clamping load and to retain that load for the life of the structure. The American Institute for Steel Construction, "Testing Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints," evaluates the effect of coatings used on the faying surfaces of slip critical, high-strength bolted connections. Typically, zinc-rich coatings (organic or inorganic) are tested to

these criteria: ASTM A 325, “Standard Specifications for Structural Bolts, Steel, Heat Treated 120/105 ksi Minimum Tensile Strength,” and/or ASTM A 490, “Structural Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength.”

Chapter 7: Surface Preparation Methods for Various Substrates

OBJECTIVES

Upon completion of this chapter, you will be able to:

OBJ 7.1: Discuss key surface preparation issues for each substrate type. Steel and Cast Iron

OBJ 7.2: Understand substrate types and factors affecting their coating application.

OBJ 7.3: Identify various standards for surface preparation.

OVERVIEW

The impact of the substrate on coating life can be substantial. There are many common themes that exist within each substrates surface preparation and factors, including:

- Ensure surface cleanliness (salts, oil, water)
- Provide an anchor profile if possible
- Ensure chemical compatibility with the substrate

The various types of substrates covered in this chapter include:

- Steel and cast iron
- Stainless steel
- Aluminum
- Galvanized
- Concrete

7.1 Steel and Cast Iron

7.1.1 Introduction

The term steel refers to a host of iron alloys. An alloy is a substance composed of two or more metals. Basic steel is composed of iron ore which has been combined with carbon. Other steel alloys also incorporate elements such as manganese, chrome, or tungsten. By varying the alloying elements, steels take on desired properties such as strength, hardness and elasticity. **Steel is the most commonly coated substrate**. Coatings are the primary method of protecting steel from natural corrosion.

7.1.1.1 Steels

Carbon steels are the most common alloy used for industrial structures, bridges, ships, and buildings. They are relatively inexpensive, readily available in a large number of shapes and sizes (rolled, wrought, and cast shapes), and have a wide range of mechanical properties. They can be heat-treated to give the best combination of strength and ductility for specific applications. They can be readily welded in both the shop and in the field.

The most common carbon steels contain about 0.2% carbon, although the carbon content can vary up to 0.6% carbon. The tensile strength of this material can range from about 40 – 200 ksi (275 – 1,400 MPa). The corrosion resistance of all the carbon steels is about the same in exposure to most environments, but may vary slightly with carbon content in some chemical environments, such as strong sulfuric acid.

Carbon steels can be alloyed with varying, small amounts of elements such as chromium, nickel, copper, molybdenum, phosphorous, and vanadium. The total alloying element content can be up to 5 percent. These alloy additions primarily enhance the steels' mechanical properties, but some of the low alloy steels have substantially better corrosion resistance in atmospheric environments than ordinary carbon steel.

7.1.1.2 Cast Iron

Cast irons contain much larger amounts of carbon than low-alloy, carbon steels, usually in the range of 2–4%. Cast iron is a low cost material and can be formed into a wide variety of shapes ready or nearly ready for final use. Most cast irons contain free carbon in the form of graphite. The shape and amount of the graphite phase has a big effect on the mechanical properties of the cast iron, particularly with respect to their ductility. The most common forms of cast iron include:

Gray cast irons contain carbon in the form of flakes and are relatively brittle

Ductile cast irons have their graphite in the form of nodules or spheroids. The ductile cast irons are the most ductile of the cast irons.

7.1.2 Surface Preparation

The preparation of the steel and cast iron substrate is important since coatings are often the primary line of defense against corrosion. Improper surface preparation can lead to abject failure of the coating causing additional cost and time expenditures. There are many types of surface preparation which are acceptable for steel. The best method may be a combination of methods.

The basic steps for surface preparation include:

- Inspection of surface
- Inspection for fabrication defects
- Pre-cleaning
- Inspection for uncorrected fabrication defects
- Cleaning
- Inspection for cleaning inadequacies

Usually supplemental information for preparing a substrate is included in the coating product data sheet provided by the manufacturer. Follow the instructions for obtaining the proper surface profile and cleanliness level. Often these instructions will include a referenced surface preparation standard. Many factors contribute to the appropriate method/process for surface preparation, including residues, rust, mill scale, anchor pattern, sharp ridges, burrs, edges, weld spatter, surface condensation, and old coatings. Steel fabrication defects must be addressed during the surface preparation process, including welds, cut edges and surface contamination. Specifically, welds can produce weld splatter and affect porosity and roughness. Cut edges need to be chamfered or rounded, and hardened material needs to be removed. Roughness needs to be ground smooth, and forms of surface contamination need to be eliminated, including oils, salts and debris.

7.1.3 Surface Preparation Standards

There is no exact correlation between NACE, SSPC, and ISO standards. NACE and SSPC are the same, but they are not equal to ISO standards.

The use of standard specifications is important in identifying mandatory and non-mandatory items. In addition, standard specifications need to identify detailed surface preparation items and criteria, such as surface profile, allowable non-visible contaminants, and inspection frequency.

There are three primary categories for cleaning of steel and cast iron surfaces. They include: 1) non-abrasive cleaning (hand/power tool cleaning and chemical etching), 2) waterjetting, and 3) abrasive blast cleaning.

The following list describes subsequent methods of non-abrasive blast cleaning of cast iron and steel:

- Solvent cleaning
- Hand tool cleaning
- Power tool cleaning
- Acid Etching (Pickling)
- Waterjetting

The table below describes the associated governing standards for those methods:

Governing Standards by Surface Preparation Method	
Waterjetting	**Power Tool Cleaning**
•NACE WJ-1/SSPC-SP WJ-1	•SSPC-SP 3
•NACE WJ-2/SSPC–SP WJ-2	•SSPC-SP 15
•NACE WJ-3/SSPC–SP WJ-3	•SSPC-SP 11
•NACE WJ-4/SSPC–SP WJ-4	•ISO 8501-1, St2 or St3
•ISO 8501-4	**Solvent Cleaning**
Hand Tool Cleaning	•SSPC-SP 1
•SSPC-SP 2	**Pickling**
•ISO 8501-1, St2 or St3	•SSPC-SP 8

7.1.3.1 Solvent Cleaning: SSPC-SP 1

Solvent cleaning is a method to remove all visible oil, grease, soil, drawing and cutting compounds, and other soluble contaminants from steel surfaces. Solvent cleaning is to be done before coating application and in conjunction with surface preparation methods specified for the removal of rust, mill scale, or paint. A variety of solvent cleaning materials may be used, including:

- Organic solvents
- Alkaline cleaners
- Acidic cleaners
- Detergents
- Emulsion cleaners
- Water/steam

Of critical importance is not just the technique but ensuring that the required cleanliness is reached. The applicator should ensure that the surfaces are indeed clean by use of the described quality assurance processes for hydro-carbon detection (UV light or water-break free tests), surface salts (test kits or surface conductivity), or visual debris.

There are many issues associated with solvent cleaning that must be considered, including determination of the need for spot cleaning versus cleaning of the complete surface. The compatibility of organic solvents with subsequent coatings is another issue that must be considered, along with the potential for rusting after aqueous cleaning. Finally, solvent cleaning is not always adequate as a final surface preparation technique. Solvent evaporation and remaining solvent residue can be an issue that must be dealt with prior to coating applications.

7.1.3.2 Hand Tool Cleaning: SSPC-SP 2

Hand tool cleaning is a method to prepare steel surfaces by using non-power, hand tools. It removes all loose rust, mill scale, paint, and other detrimental foreign matter.

Hand tool cleaning is not intended to remove adherent mill scale, rust, and paint. Mill scale, rust, and paint are considered adherent if they cannot be removed by lifting with a dull putty knife. Hand cleaning is one of the oldest methods of non-abrasive cleaning**.** Hand cleaning tools include wire brushes, scrapers, chisels, knives, chipping hammers. illustrates an array of hand cleaning tools. Since these tools do not provide a highly efficient process for surface preparation, the applicator should ensure that all loose rust, paint, etc. are indeed removed with the tools.

7.1.3.3 Power Tool Cleaning: SSPC-SP 3, SP 15, and SP 11

Power tool cleaning prepares steel surfaces with power-assisted hand tools. It is intended to remove all loose rust, mill scale, paint, and other detrimental foreign matter, but is not intended to remove adherent mill scale, rust, and paint.

The following standards apply to power tool cleaning:

- SSPC-SP 3, “Power Tool Cleaning,” method of preparing steel surfaces by use of power assisted hand tools
- SSPC-SP 15, “Commercial Grade Power Tool Cleaning,” provide commercial grade power tool cleaned steel surface; retain or produce minimum 25 micrometer (1.0 mil) surface profile
- SSPC-SP 11, “Power Tool Cleaning to Bare Metal,” produce bare metal surface; retain or produce minimum 25 micrometer (1.0 mil) surface profile

As in SSPC-SP 2, mill scale, rust, and paint are considered adherent if they cannot be removed by lifting with a dull putty knife.

Power tool cleaning is frequently used in maintenance operations. In addition to removing loose mill scale, rust, and paint, it is also used to remove weld flux, weld spatter, laminations, and to smooth rough welds and round out gouges before abrasive blast cleaning.

Power tool cleaning equipment includes: rotary wire brushes, impact tools, grinders, and sanders. While power tools will are more efficient than hand tools for surface preparation, their physical size and configuration does not always enable them to reach all surface areas, especially on complex surfaces. For such areas, it is important that the applicator comes back using hand tools (SSPC-SP 2) to prepare such areas.

The following power tool cleaning issues should be observed: different tools leave very different textures; a variety of tools may be required for surfaces with varied geometries; and productivity changes with wear (brush, wheel, needles, etc.).

7.1.3.4 Surface Preparation by Waterjetting: NACE WJ-1/SSPC WJ-1, NACE WJ-2/SSPC WJ-2, NACE WJ-3/SSPC WJ-3, NACE WJ-4/SSPC WJ-4

The following criteria identify high level differences:

- Low pressure water cleaning (below 5,000 psig)
- High pressure water cleaning (5,000 to 10,000 psig)
- High pressure waterjetting (10,000 to 30,000 psig)
- Ultrahigh pressure waterjetting (above 30,000 psig)

Water cleaning uses pressurized water, removes some contaminants, and is generally used prior to other surface preparation methods or the application of maintenance coatings. On the other hand, waterjetting uses high-pressure water above 10,000 psig, prepares the surface for coating, does not leave a measurable profile, reveals existing profile, and cleans deep inside pits in the existing profile.

This specification addresses using a high energy stream of water to remove existing corrosion or coatings and clean surfaces before coating. The technique offers advantages over dry abrasive blasting by minimizing contamination of other local equipment and improving production time for most projects. Waterjetting effectively removes harmful water-soluble surface contaminants that may not be removed by dry abrasive blasting alone. Waterjetting is also used to remove surface grease and oil and shotcreting spatter.

It should be understood, however, that waterjetting exposes the original surface profile. If there was no acceptable surface profile to start (and this is a cause of the coating failure necessitating the recoating work) waterjetting will not create the necessary profile. The water used for waterjetting should also be “clean.” Contamination on substrates can be a leading cause of coating failure. Waterjetting with salt-containing water can actually enhance the failure of coatings applied. This can happen when a poor quality source of original water is used or if the jetting water is recycled without adequate filtration.

NACE and SSPC describe four levels of visible cleanliness including the extent of remaining rust, dirt, previous coatings, mill scale and foreign matter:

- WJ-1, Clean to Bare Substrate (all removed)
- WJ-2, Very Thorough Cleaning (5% tightly adherent thin coatings and foreign matter)
- WJ-3, Thorough Cleaning (33% tightly adherent thin coatings and other foreign matter)
- WJ-4, Light Cleaning (any amount that is tightly adherent can stay)

The following issues should be considered when waterjetting: the capture and disposal or treatment of water and effective drying, such as water seeping from crevices.

A last concern with any sort of wet surface preparation is the possibility of “flash rusting” after the process is complete. Application of water to the steel will create natural conditions to cause corrosion of the substrate. The degree of corrosion that creates damage to the coating is a matter of substantial debate in the industry.

Appendix A of the standards attempts to define different levels of flash rusting, yet these remain highly problematic and open to wide interpretation. In general, it appears acceptable that painting over “light” flash rusting is acceptable for most applications, but the applicator should confirm and understand the requirements of the application specification.

Some waterjetting procedures may recommend the use of a corrosion inhibitor within the water to eliminate flash rusting. Studies concerning the effects of these inhibitors on coating life remain non-conclusive. Some owners believe them to be acceptable and others believe that they contribute to subsequent blistering of the coating by acting as a soluble contaminant under the

coating. The applicator should ensure that the owner and the paint supplier accept the use of any corrosion inhibitor before using one in a waterjetting process.

7.1.3.5 Abrasive Blast Cleaning

There are several industrial specifications that govern the application of abrasive blasting. NACE and SSPC have issued joint standards, which include:

- NACE No. 1/SSPC-SP 5, White Metal Blast Cleaning
- NACE No. 2/SSPC-SP 10, Near-White Metal Blast Cleaning
- NACE No. 3/SSPC-SP 6, Commercial Blast Cleaning
- NACE No. 4/SSPC-SP 7, Brush-Off Blast Cleaning
- NACE No. 8/SSPC-SP 14, Industrial Blast Cleaning

7.1.3.6 Air Abrasive Blasting

ISO standards can also be used for abrasive blast cleaning standards; however, they are only similar to NACE and SSPC standards and have no exact correlation between them. The following list describes applicable ISO standards:

- ISO 8501-1, SA 3, Blast-Cleaning to Visually Clean Standards
- ISO 8501-1 SA 2.5 Very Thorough Blast-Cleaning
- ISO 8501-1, SA 2, Thorough Blast-Cleaning
- ISO 8501-1, SA 1 Light Blast-Cleaning

Material characteristics are important in abrasive blasting. The size and shape affect the cleaning rate as well as the resultant surface profile (rounded versus angular profile). The breakdown rate of the abrasives affect whether or not they can be recycled (used more than once) or if they embed in surface being blasted. Finally, material compatibility is an important consideration. Steel abrasives should not be used on aluminum, and metallic abrasives should not be used on stainless steels.

The following list describes specific considerations for abrasive blasting:

- Surface to be cleaned
- Size and shape of object to be cleaned
- Type of cleaning facility (outdoor/indoor or cabinet versus blast room)
- Existing surface condition
- Desired condition after cleaning
- Type of coating to be applied
- Desired surface profile
- Abrasive recycling

There are two primary methods of abrasive blasting: manual and automated (centrifugal blast). Manual abrasive blasting includes dry, wet, slurry, and high pressure water blast methods. The abrasive mix operation develops within blast machine, and various amounts of new and fractured abrasives are automatically maintained by blast machine. Vacuum blasting provides for the safe removal of contaminated material. It is commonly used for steel and concrete. The contaminant, coating, corrosion, and abrasive are vacuumed into a closed compartment.

7.2 Stainless Steels

There are a wide range of stainless steels which are used for their corrosion resistance in many natural and chemical environments. It cannot be overemphasized, however, the corrosion resistance of each type of stainless steel depends heavily on their specific environment. Stainless steel is not only coated to improve corrosion resistance, but it also reduces stress cracking and reflectance and provides an means of color coding.

Stainless steels are grouped into families with common characteristics. These groups and a short description of the characteristics of the alloys in each group are provided below:

- Martensitic and Ferritic Stainless Steels**: AISI 400 Series** Stainless Steels
  - Stainless steels with 12% to 30% chromium and minor other additions
  - High strength, magnetic
  - Subject to pitting and stress cracking; difficult to weld
  - Used in pump components, fasteners, valve trim, turbine blades, tray components in refinery distillation towers
- Austenitic Stainless Steels: **AISI 200 and 300 Series** Stainless Steels
  - Typical alloys contain 17% to 25% chromium and 9% to 10% nickel
  - High strength; non-magnetic
  - Subject to pitting and stress cracking
  - Used in heater tubes, heat exchangers, piping, tower trays, reactor internals, vessel linings
- Precipitation-Hardening Stainless Steels: **AISI 600 Series** Stainless Steels
  - Hardened and strengthened by solution quenching, followed by a precipitation aging treatment at 800ºF to 1,100ºF (427ºC to 593ºC)
  - Aging minimizes scaling, distortion, and cracking
  - Susceptible to chloride and sulfide stress corrosion cracking
  - Used for valve seats, pump shafts, pump wear rings, and impellers
- Duplex Stainless Steels
  - Proprietary formulation
  - Improved corrosion resistance; not generally subjected to stress cracking
- Specialty Stainless Steels

Sometimes it is difficult to achieve coating adhesion to stainless steel surfaces. Usually this happens because of inadequate surface preparation, especially where abrasive blasting is being used. Many stainless steel products are provided in a cold rolled or smooth, polished finish which limits coating adhesion. Because they are inherently corrosion resistant, they are not always coated.

Stainless steels can be much harder than standard low-alloy, carbon steels. Furthermore, some of the alloys, especially the 300 series austenitic stainless steels, can work-harden. Work-hardening is a metallurgical response of the alloy in which the surface of the material becomes stronger due to the deformation of blasting. After a period of time, continued abrasive blasting under the same conditions produces no further profile-generation; therefore, it is important to ensure you are using the correct abrasive size and air pressure to create the required profile. Do not use metallic abrasive or copper slag. Glass, aluminum oxide, and garnet are commonly used abrasives.

Coating application and selection should include the following steps: 1) identify the purpose of the coating, and 2) consult the manufacturer’s data sheets for the appropriate coating. Specific purpose such as supplemental corrosion protection and safety are important in specifying the coating. There are a wide range of chemistries, such as acrylic, epoxies, alkyds, epoxy-phenolic, etc. These chemistries can be identified using the manufacturer’s data sheets.

7.3 Aluminum

Aluminum and aluminum alloys are widely used when weight is significant. In some chemical handling uses, aluminum is used since it has better corrosion resistance than other materials.

It is a reactive metal, but it is passive in many mildly corrosive environments because of the formation of a thin transparent film of aluminum oxide. In more corrosive environments, this film can break down and corrosion can occur.

The film is generally stable in neutral and oxidizing acidic environments. The film is generally unstable in reducing acids, alkaline environments, and environments containing chlorides. The oxide film on aluminum alloys can be artificially thickened through a chemical treatment called anodizing.

Aluminum alloys are grouped into series. The series of aluminum alloys is based on the primary alloying elements used. A series list and the alloys' important characteristics are given in Aluminum Alloys.

Table 7.1: Aluminum Alloys

Series	Primary Alloying Elements	Relative Corrosion Resistance(A)
1000	None	Excellent
2000	Cu	Fair
3000	Si/Mn/Cu/Mg	Good
4000	Si	Good-Fair
5000	Mg	Excellent-Good
6000	Mg + Si	Good
7000	Zn	Fair

(A) Represents corrosion resistance in atmospheric exposure. Behavior will vary for other environments.

Surface preparation of aluminum for coating can be broken into two categories:(1) mechanical surface preparation, including abrasive blast cleaning, hard or power tool cleaning, or barrel finishing, and (2) chemical cleaning, including solvent cleaners, emulsifiable solvents, alkaline cleaning, and acid cleaning.

For use as chemical containers or ship hulls, the thickness of the aluminum is sufficient to support abrasive blasting or some other form of mechanical surface preparation. Because many aluminum applications are intended to save weight, the material may not be extremely thick, for example, the skins of aircraft. This surface cannot be abrasive blasted without destroying it.

Surface preparation methods for aluminum vary according to the intended application and the specified coating. Surface preparation involves both mechanical and chemical techniques.

7.3.1 Mechanical Surface Preparation of Aluminum

Abrasive blasting with dry nonmetallic is one of the simplest and most cost-effective methods for cleaning aluminum surfaces. Abrasive blasting removes scale, sand, and mold residues from castings.

Aluminum oxide, garnet, and slag abrasives are commonly used for blast cleaning aluminum alloys. In many specifications, aluminum oxide is preferred, especially for the final surface

preparation. Using steel grits can be problematic. Sometimes when aluminum is blasted with steel grit, particles become embedded in the surface and unless removed by a subsequent chemical treatment, will rust and stain the aluminum surface. Pickling in nitric acid removes the steel particles and maintains the corrosion resistance of the coating.

The standards applied to aluminum abrasive blasting in industrial applications are often derivatives of those applied to steel. Obviously, the nature of the appearance of the base metal is somewhat different, but the ability to judge residual staining, blast profile, and surface cleanliness remain, using the same processes that one would apply for low-alloy carbon steels. Thus similar terminology will exist for abrasive blasting requirements for aluminum and steels.

Aluminum can be work-hardened by over blasting, and because it is a soft substrate, mechanical cleaning should not remove unnecessary substrate material.

7.3.2 Chemical Surface Preparation of Aluminum

For aluminum surfaces not amenable to mechanical surface preparation, they should be chemically prepared to accept organic coatings. Usually, this means that they will be cleaned and have a conversion coating applied (dip or spray techniques) before receiving the final organic coating. Aluminum surfaces can be chemically cleaned with solvents, alkalis, and acids. These chemicals may be used alone or in combination with other cleaning systems, and they typically involve multiple pre-treatment steps including cleaning, treating and rinsing steps. A line of immersion tanks are normally used during these pre-treatment steps; however, a few pre-treatments can be spray applied.

Solvent cleaners are used primarily to remove oil and grease compounds. Normally, organic solvents alone are unable to completely clean the surface. However, they are effective in removing large quantities of organic contaminants in preparation for further cleaning with alkaline cleaners. Heating, agitation, or mechanical action may also be required for satisfactory cleaning. Compounds burned into the aluminum surface may need to be removed by soaking in a liquid, organic degreaser, such as trichloroethylene or methylene dichloride.

Alkaline cleaning is the most common method for cleaning aluminum and aluminum alloys. It is easy to use in production operations and uses low-cost equipment. Aluminum is susceptible to attack by alkaline solutions. Most alkaline cleaning solutions maintain a pH between 9 and 11 and are often inhibited to minimize attack on the aluminum substrate.

Aluminum surfaces sometimes contain pockets of localized corrosion (atmospheric etch) that result from contaminants in the air during storage. These areas become more apparent after alkaline cleaning and, when present, the substrate is dipped into either a sodium bisulfate solution or a cold nitric acid solution to minimize the action of the subsequent alkaline cleaner.

Acid cleaners may be used to remove surface oxides from aluminum surfaces prior to resistance welding, organic coating application, conversion coating, bright dipping, etching, or anodizing. A mixture of chromic and sulfuric acids is commonly used to remove surface oxides, oil burned into the surface, water stains, and other films, such as the iridescent and colored films formed during heat treating. The acid solution cleans and slightly etches the surface. Other acid combinations or nonpolluting products free of chromic acid may also be used.

7.3.3 Conversion Coatings

Chemical conversion coatings applied to aluminum are adherent surface layers of low-solubility oxide, phosphate, or chromate compounds produced by the reaction of various reagents with the aluminum surface. Conversion coatings affect the following properties of the aluminum substrate:

- Appearance
- Electrochemical potential
- Electrical resistivity

- Surface hardness
- Absorption
- Conversion coatings provide the following benefits:
- Excellent corrosion resistance under organic finishes or oil and wax films
- Improved adhesion of organic finishes
- Mild wear resistance
- Enhanced drawing or forming characteristics
- Corrosion resistance without materially changing the electrical resistivity of the substrate
- Decoration when colored or dyed

Phosphate conversion coatings can be a light bluish-green to olive-green in color. Phosphate-chromate coatings are used extensively on aluminum to provide galvanic protection from steel materials such as brushings or inserts.

Chromate conversion coatings are used for maximum corrosion resistance. These coatings vary from clear and iridescent to light yellow or brown depending on the composition of the aluminum-based material and the thickness of the film. Chromate coatings exhibit low electrical resistivity and therefore, are widely used on aluminum surfaces for application in the electronics industry. While chromates have historically been used for their corrosion inhibition, they are being replaced due to environmental and worker health reasons.

7.3.4 Anodized Aluminum

Anodized aluminum usually provides an excellent substrate for accepting a coating without further treatment, other than ensuring that the surface is clean. Anodized aluminum is actually a highly tenacious surface-oxide layer built up chemically or electrochemically on the surface of the aluminum. An anodized finish on high-purity aluminum may be almost transparent or highly colored.

Three principal types of anodizing processes are the chromic-acid process, the sulfuric acid process, and hard-anodizing processes which use sulfuric acid either with or without additives.

For coating, the key is to recognize that the somewhat porous and micro-rough surface of most anodizing is excellent for coating adhesion. The key concern is to make sure that one does not apply any subsequent mechanical surface preparation which would primarily act to damage a readily painting able substrate.

In general aluminum is anodized to:

- **Increase corrosion resistance** — Aluminum oxide acts as a barrier to atmospheric and salt-water attack.
- **Increase coating adhesion** — Anodic coatings provide a chemically active surface that promotes coating adhesion. Aluminum work pieces that are coated for service in severely corrosive environments are anodized prior to coating application.
- **Permit subsequent plating** — The porosity of anodic films enhances the electroplating process.
- **Improve adhesive bonding** — A thin phosphoric acid coating over an anodized surface increases bond strength and durability.
- **Improve decorative appearance** — Anodic coatings are lustrous and are used in applications where the natural appearance of the aluminum is preferred. The degree of luster depends on

the condition of the aluminum substrate prior to anodizing. Dull etching of the surface decreases luster. Processes such as bright etching and buffing increase luster. Colored anodic coatings are also available to enhance the appearance of the aluminum surface. Organic dyes and certain mineral pigments can be absorbed by the coatings to provide a wide variety of colors.

- **Provide electrical insulation**.
- **Increase abrasion resistance**.
- **Help detect surface flaws**.

7.4 Galvanized Steel

Galvanizing is the primary process by which zinc is applied to steel. Two different French engineers suggested it at approximately the same time (1840). Since then, its use has steadily increased.

Galvanizing is the process of cleaning steel free of all mill scale or other impurities and then dipping the steel into molten zinc. The molten zinc wets clean steel very readily and alloys with the steel, making a strong bond between the zinc and the steel surface. One of the great advantages of galvanizing is that once the object is dipped, removed, and cooled, the process is finished and the galvanized object can be handled without fear of damage. The hot dipped galvanized coatings are rugged and provide a long-lasting barrier against most atmospheric corrosion. While galvanizing changes the appearance of the metal, it has several advantages, including, the zinc extends the service life, it provides color coding and safety marking, and it eases repainting.

After being applied, the zinc will react with the oxygen in the atmosphere to form zinc oxide. This zinc oxide layer then further reacts with the atmosphere, first to form zinc hydroxide in a reaction with water molecules, and then with carbon dioxide to for zinc carbonate. The zinc carbonate forms a protective film, a stable state layer, on the surface of the coating.

Coating galvanized steel surface can be problematic. Proper surface preparation is a critical factor in achieving good paint adhesion on galvanized surfaces. Preparation requires effective cleaning and a proper surface profile. Surface preparation methods vary according to the condition of the galvanized coating. The following classifications are used for galvanized steel:

- Newly galvanized steel
- Weathered galvanized steel

7.4.1 Newly Galvanized Steel

Newly galvanized steel (less than 48 hours old) typically has a very smooth surface that may need to be slightly roughened to enhance paint adhesion. With little or no zinc oxide or zinc hydroxide present, the surface does not require major cleaning. The most common methods of cleaning newly galvanized surfaces include alkaline cleaning, solvent cleaning, and ammonia cleaning. The type of cleaner varies according to how it will react with a specific coating system and the degree of weathering of the galvanized coating. The coating manufacturer should be consulted for recommended cleaning instructions.

Alkaline Cleaning. Alkaline solutions used to remove oil, grease, and dirt must have a pH of 11 to 12, but not greater than 13. Solutions can be applied through dipping, spraying, or brushing. When brushing, a soft, nylon bristle brush is used; copper or steel brushes are not recommended. A water-based emulsifier can be used to remove contaminants. After alkaline cleaning, the surface must be rinsed with hot water and allowed to dry completely.

Solvent Cleaning. Typical cleaning solvents include mineral spirits, turpentine, and high-flash naphtha. These solutions are applied with lint-free rags or soft, bristled nylon brushes; these are

changed often to prevent re-spreading of the contaminants. After solvent cleaning, the surface is rinsed with hot water and allowed to dry completely.

Ammonia Cleaning. Ammonia cleaning is typically reserved for galvanized surfaces with ash residue. A solution of 1% to 2% ammonia is applied with a nylon brush; after cleaning with the ammonia solution, the surface is thoroughly rinsed with hot water and allowed to dry.

After the cleaning of the surface, the galvanized substrate is then either profiled or etched via a pretreatment to provide an improved anchor pattern for subsequent paint to adhere. Water blasting or brush-off (sweep) abrasive blasting in accordance with SSPC SP-7 can be used to roughen the smooth surface. Aluminum/ magnesium silicate has been used successfully to blast galvanized steel without removing too much of the galvanized zinc coating. It is critical to ensure that any mechanical process DOES NOT remove measurable zinc. Organic abrasives such as corn cobs, walnut shells may also be used; be sure that these organic materials do not impart an oil on the surface. Sweep blasting while the galvanized work-piece is still warm (175°F to 390°F [79°C to 199°C]) generates an excellent surface profile. When blasting under ambient conditions, best results are obtained when the relative humidity is less than 50% and the temperature is no lower than 70°F (21°C).

Suitable pretreatments include products such as a zinc phosphate or a wash primer. A zinc phosphate is a conversion coating used to increase the adherence and durability of a paint film. The phosphate treatment is applied by immersion, spray, or a soft bristled, nylon brush. The work piece is washed with clean water after phosphate application and allowed to dry completely. Wash primers use a metal conditioner to neutralize surface oxides and hydroxides and to etch the surface. Wash primers are best applied in shop conditions to obtain optimum thickness between 0.3 mils and 0.5 mils (8 µm and 13 µm). Thicknesses above 0.5 mils (13 µm), may cause adhesion problems.

7.4.2 Weathered Galvanized Steel

Before painting partially weathered galvanized steel, it is important to know if the hot-dip galvanized coating was chromate quenched. Spot testing the galvanized steel according to ASTM B 201, “Standard Practice for Testing Chromate Coatings on Zinc and Cadmium Surfaces,” can be used to identify the presence of chromate conversion coatings. If present, the chromate layer must be removed by (1) brush-off blast cleaning, (2) abrading the steel by sanding, or (3) allowing the steel to weather for six months. Surface contaminants that may result from weathering may adversely affect coating performance and must be removed as well.

Partially weathered galvanized steel should also be inspected for wet storage stains. Wet storage stains can severely interfere with paint adhesion. If present, wet storage stains can be removed by carefully brushing the stains with a mild ammonia solution, such as diluted household ammonia. Removal of severe wet storage stains may require the use of a mild acid solution, such as one part acetic acid mixed with twenty-five parts water. Either cleaning procedure should be followed by rinsing with warm water.

Partially weathered galvanized steel surfaces should also be slightly roughened to improve paint adhesion. Any of the profiling methods previously discussed may be used. Penetrating sealers are particularly effective in providing a surface profile for partially weathered galvanized steel surfaces.

Fully weathered galvanized steel has a completely formed zinc patina, which provides a stable and finely etched surface. The only surface preparation required is a warm water power wash to remove loose particles from the surface. The pressure should not exceed 1,450 psi (10 MPa). The surface must be completely dry before painting.

7.4.3 Coating Selection

The following coatings are preferred coatings for direct use over galvanizing:

- Organic zinc-rich paints

- Acrylics
- Aliphatic polyurethanes
- Bituminous coatings (no UV exposure)
- Coal-tar epoxies (buried conditions)
- Epoxy-polyamide cured
- Latex-acrylics
- Portland cement in oil
- Vinyls (require sweep blast or wash primer)
- Powder coating (except polyesters)

7.4.4 Maintenance Coating

Galvanized steel with rusted areas is really just a combination of two conditions – weathered galvanizing and rusted bare steel. Surface preparation and coating needs to consider these two conditions.

The rusted steel must first be power-tool cleaned (SSPC-SP 3 or SSPC-SP 11) to remove rust and loose coating. SSPC-SP 11, "Power Tool Cleaning to Bare Metal," is preferred because it not only removes all visible rust, but also produces a roughened surface. Powered needle guns and grinders with flexible wheels and disks can be used to produce an SSPC-SP 11 surface. The cleaned steel should be primed with an organic or inorganic zinc primer the same day to prevent surface rusting. If surface rusting occurs, the surface must be re-cleaned.

The surfaces with remaining, intact galvanizing should be inspected to determine if they are partially or fully weathered. Based on the weathered state of the galvanizing, the appropriate methods discussed in the above sections should be used. The topcoat selected for the galvanizing should be compatible with the zinc-rich repair coating so the final surface has a uniform, continuous topcoat.

Consulting the coating manufacturer prior to selecting a coating system for galvanized surfaces is always a good idea. Different physical and chemical characteristics of generic coatings may have varied reactions with galvanized surfaces.

7.5 Concrete Substrates

Concrete is a widely used construction material. Concrete can resist attack by sun, rot, (some) chemicals, and most bacteria and fungi without the aid of protective coverings. However, concrete exposed to a corrosive environment is sometimes coated to extend its life or provide aesthetic properties. Barrier-type coatings are normally used to protect concrete when required.

Concrete is typically a mixture of Portland cement, aggregate, and water that hardens to form a solid mass. The properties and qualities of concrete vary significantly depending on the type and quality of materials and the amount of water added. Desirable properties of concrete include inorganic, abrasion resistance, good compressive strength (but poor tensile strength), and increasing hardness and compressive strength with age. Concrete and concrete products are usually made locally because of their heavy weight and high transportation costs. As a result, a wide range of source materials is used to make concrete.

When Portland cement is mixed with enough water to form a paste, the cement compounds begin to react and form a crystalline structure that binds the sand and stone into a hardened mass. The hardened mass is called concrete.

Concrete can be made with many different types of aggregates. Some of these include river sand, granite, limestone, and various types of fibrous aggregates such as glass and asbestos. Each mix of cement and aggregate can create a different surface.

Concrete undergoes a complex curing process involving hydration, where it continues to cure long after it hardens. Often, it may be days or weeks before concrete is put into service or prior to its coating application. Some coatings are designed as curing membranes and can be applied immediately to facilitate cure.

Concrete surfaces may be classified as follows:

Cast-in-Place (poured). Cast-in-place concrete is poured with a high moisture content to allow the concrete to flow into the form. Laitance, holes, and air bubbles are commonly encountered in cast-in-place concrete, even on vertical surfaces. Proper vibration, rodding and other techniques are used to remove the air pockets; however, they can have the negative effect of working the aggregate to the bottom. Laitance forms on the exterior surface, and it has a weak combination of sand and cement, which is not a stable surface for coatings. Other concrete substrate problems that can affect coating applications include pinholes, subsurface voids, rock and air pockets, tie holes from tie wires, offsets at junctions, honeycombing, and form release compounds.

Concrete masonry units (CMU) are also called concrete blocks, cement blocks, foundation blocks and cinder blocks. They are standard building materials frequently used in corrosive conditions. The surface created by block construction can have depressions and cavities as well as irregularities at the joints between the blocks. In addition, the mortar used to join the blocks can vary with the materials used to produce them, as well as the method of installation.CMU surfaces are generally sealed prior to the application of any coating. Because of its porosity, its tendency to crack, and the presence of mortar joints, concrete block is very difficult to coat for effective immersion service.

Special concrete surfaces include shotcrete and reinforced concrete.

Shotcreting is the process of spraying or slinging shotcrete onto a surface as a coating to restore concrete to its original grade. Shotcrete is a dense mixture of cement and relatively small aggregate and has low moisture content. A filling agent is often added to help hold the shotcrete in place until cured.

Coatings of up to 4 in. (100 mm) thick are common. Unless they are troweled smooth, shotcrete surfaces are unusually rough and dense, but they have few pinholes, air pockets, and subsurface cavities. They are sometimes referred to as gunited surfaces.

Fiber reinforcement can be added to concrete to improve the tensile strength. Asbestos cement and glass-fiber cement products are two examples of fiber reinforcement

Asbestos cement products have higher tensile strength than other concretes, but they may be brittle. Due to health considerations, these products are no longer used, but they may be found when rehabilitating existing structures.

Glass-fiber cement products contain glass fiber for reinforcing. This results in a concrete which has high impact resistance, increased tensile and bending strength and an overall decrease in weight. Note that the proper glass fiber material must be used as many are susceptible to alkali attack by hydrated Portland cement

Concrete has a variety of uses and applications across many industries, as well as advantages over other materials. Some of the application and advantages include decoration, waterproofing, enhancing chemical resistance, protection from freeze-thaw cycles, protection of reinforcing steel, decontamination, secondary containment, surface sealer, protection against abrasion and erosion, color coding, protecting purity of water or other products contained, improving and simplifying cleaning, and skid resistance.

7.5.1 Concrete Surface Preparation

Proper surface preparation is the key to successful coating and lining performance with any substrate, including concrete. Effective surface preparation produces a concrete surface that is acceptable for the application of the required protective coating. Absorbed contaminants and loose material on the concrete surface that may interfere with coating adhesion or shorten service life must be removed. Protrusions such as form burrs, sharp edges, fins, and concrete spatter must also be removed.

Surface preparation of concrete normally takes more time and money than the actual coating application. The surface preparation methods used are determined by the specific condition of the concrete and the requirements of the coating system to be applied. In addition, if the concrete surface requires repair, the methods used must reflect the coating requirements for the intended service condition.

Surface preparation of concrete and other cementitious surfaces generally includes the following activities:

- Inspection of the concrete surface prior to surface preparation
- Precleaning
- Steam cleaning
- Chemical cleaning
- Surface preparation
- Mechanical surface preparation
- Chemical surface preparation
- Cleaning (if required)
- Inspection of prepared surfaces
- Treatment of cracks and expansion joints
- Final inspection of the prepared concrete surface

Inspection prior to surface preparation includes identification of the following items:

- Form-release oils
- Expansion-joint locations
- Residues (dirt, chemical salts, or other foreign substances)
- Ice or ice crystals
- Liquid water on surface
- Laitance
- Pits
- Voids
- Efflorescence
- Projections
- Porosity
- Moisture content
- Curing compounds on surface

Pre cleaning involves the removal of chemical contaminants, grease, and oil, and it can be done by steam cleaning or chemical cleaning. Steam cleaning includes heat and jetting action to improve its effectiveness and may also be combined with the use of detergents. Chemical cleaning involves a range of acid and alkaline products; however they must not leave a residue within the concrete substrate.

The surface to be coated is typically prepared by mechanical methods, some sort of abrasive blasting (dry, wet, vacuum assisted or centrifugal shot), or UHP waterjetting. It is essential to generate the required profile without damaging the concrete or creating an excessive profile. Mechanical preparation usually reveals some voids or "bug-holes" in the concrete that need to be filled prior to coating.

Abrasive blast-cleaned concrete has an anchor pattern different from abrasive blast-cleaned steel. International Concrete Repair Institute (ICRI) Guide No. 03732, "Guideline for Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings and Polymer Overlays" contains a document and comparator set to use to select an appropriate method of concrete surface preparation.

Dry abrasive blasting concrete is very different from blasting steel. Concrete is less resistant to abrasive action so it requires significantly less blast time than steel. Other practical factors to consider when dry abrasive blasting concrete include using:

- Finer abrasives than on steel
- Lower pressures than on steel
- Faster movement over the surface (avoids gouging and exposing large areas of bare aggregate)

Over-blasting can result in a very high initial surface void area. This can greatly increase the amount of primer needed and can create substantial problems. Abrasive blast-cleaned concrete may need a finish coat of mortar, a primary coating system applied directly, or a sealer coat applied before the primary coating.

Because each concrete surface can be unique, the techniques should first be tried as a test on a smaller area of the surface before being used on the entire substrate. Train the operators to

recognize if the surface mechanical properties are changing across the surfaces, indicating the desired profile is being achieved or exceeded. Either case will require a modification of technique.

NACE No. 6/SSPC-SP 13, "Surface Preparation of Concrete" covers the preparation of concrete surfaces prior to application of protective coating or lining systems, including mechanical, chemical or thermal methods of surface preparation. The process described in the NACE No. 6 standard is generally quite comprehensive. The key concerns are inherently related to the porous nature of the concrete and its chemical nature.

Unlike (most) steels or other metals, a primary concern with concrete is its inherent porosity — even with "dense" concrete, sufficient pores and micro-pore exist to trap moisture and other contaminants. On a steel surface, oils and greases will typically sit on the surface of the material and not penetrate within the metallic lattice work. In concretes, the opposite can happen. Oils and other contaminants can penetrate within the pores of the concrete; the degree to which this may happen will depend from case to case on the source of contaminants and the pore density and size within the concrete. In some cases, core samples may be required to determine the depth of penetration of such contamination.

7.5.1.1 Water

Water and/or steam are very powerful solvents and are effective surface cleaners. Water blast cleaning and waterjetting are surface preparation methods for concrete substrates. Low and high pressure water cleaning and waterjetting remove contaminants, laitance, and weak concrete. It can expose subsurface voids. Water cleaning and waterjetting can be enhanced with chemical cleaners or abrasives for a more effective surface preparation/cleanliness. The concrete surface must be sufficiently dry prior to coating. Operators must be aware that ultrahigh pressure waterjetting (above 30,000 psi [210 mpa]) can destroy concrete; however, hydrodemolition pressures serve to assist is purposeful concrete demolition operations.

7.5.1.2 Hand and Power Tool Cleaning

There are a variety of methods for mechanically removing loose or weak concrete and surface protrusions. Scarifiers, scabblers, and terrazzo machines are just some of methods/equipment for cleaning concrete substrates.

The effectiveness of using hand and power tools to clean concrete surfaces varies on the tool and/ or the technique used. Using hand and power tools can be a fairly slow and costly process. These tools remove loose and powdery (weak) concrete at the surface, but they do not open air pockets as effectively as abrasive blasting does.

7.5.1.3 Acid Etching

Surfaces can also be cleaned chemically, using appropriate acids to etch the surface. This usually has to be limited to horizontal surfaces (floors). This is because it is difficult to get enough contact time for the acid to dissolve or eat away some of the Portland cement binder; obviously this is difficult on vertical or slanting surfaces. Acid etching also exposes fine aggregate and provides a surface profile on horizontal concrete surfaces. Acid etching is not an aggressive method of surface preparation. It is used to lightly roughen smooth concrete surfaces, such as hard steel-troweled floors.

For surfaces contaminated with alkalies, acid etching chemically neutralizes the alkaline concrete surface. Hydrochloric acid (muriatic acid) is typically used at a ratio of 10 parts to 20 parts concentrated hydrochloric acid with 80 parts to 90 parts water.

To etch a surface the acid is applied using a sprinkler can or low-pressure sprayer. When the reaction is complete, the salts formed (primarily calcium chloride, which is highly soluble in water) should be scrubbed and thoroughly washed from the concrete surface. Several etchings may be needed to do the job. Therefore, acid etching should only be considered when other surface preparation methods are difficult or impractical to use.

After etching and rinsing the surface, use pH paper to determine whether the surface is alkaline or acidic. Determine the pH according to ASTM D 4262, "Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces."

After rinsing, allow the clean concrete to dry thoroughly before application of the coating.

7.5.1.4 Smoothing Surfaces

A unique factor is preparing concrete with cracks. Cracks in concrete are typically two types **(1)** static (stable) and **(2)** active (moving). Static cracks can be caused by settlement and are no longer moving. These are usually cleaned to remove dust or fine particles in the cracks and then injected with a chemically curing product (epoxy grout) before coating.

Active cracks are more difficult to prepare. A crack sealer is not generally effective, (injecting a material into the crack can cause mechanical stress elsewhere and new cracks form). If the structure is moving, it is a better idea to find out what is causing the movement and find ways to stop it. If this is not possible, it may be necessary to install an expansion joint adjacent to the damaged area to control the crack growth and then fill the crack with an epoxy grout.

After surface preparation, use visual checks or QA tests to ensure there is no more oil/grease contamination or excess moisture. Neither should there be any residual laitance, efflorescence, rough projections, residual salts, dust, or other foreign substances. When clean, coat according to the standards established by the coating manufacturer.

7.5.1.5 Fiber-Reinforced Plastic (FRP)

Fiber-reinforced plastics are increasingly used due to their excellent corrosion resistance and light weight. They are a composite of an organic resin and fiber-reinforcement. Both resin and fiber can be manufactured from a variety of products. Common resins include epoxy, polyester, vinyl esters, and phenolics. Examples of fiber are glass, Kevlar, or graphite strands. Again, a wide range of fibers are manufactured. The finished products consist of layers of resin surrounding the fiber reinforcement. The reinforcement can be laid in varying patterns to increase mechanical strength. Additives may be included in the package to increase fire resistance or provide color. Coatings are used to provide final aesthetic appeal, UV protection, or increase the chemical resistance of the finished product.

Before coating these surfaces need to be cleaned using appropriate solvents by the processes described in SSPC-SP 1, "Solvent Cleaning." Surface roughening for is done by via careful mechanical processes or hand sanding. The reinforcing fiber should not be exposed — if this happens consult with FRP system designer to make correct repairs before coating is done.

Chapter 9: The Coatings Specification

OBJECTIVES

Upon completion of this chapter you will be able to:

- Understand why coating specifications are important.
- Understand elements of the coating specification.
- Develop a complete and unambiguous coating specification.
- Identify where shortcomings in or departures from the specification can harm coating life.

The coating specification is like a road map to how the project will unfold, so it is critical that the specification is detailed and unambiguous. This section will address:

- The role of the specification.
- How to create a specification.
- Elements of the specification.
- Implementing and administering the specification.
- Departures from the specification.
- Specification shortcomings.
- Effect of specification elements on service life of the coating

SSPC-TR 4/NACE 80200, Preparation of Protective Coating Specifications for Atmospheric Service is a joint technical report that describes current practices to prepare a protective coating specification for atmospheric service. Review the technical report in addition to the material in this chapter.

9.1 The Role of the Specification

A specification is a formal, contractual guidance document that outlines the project requirements to which all parties are held accountable. It is typically written by the owner of the structure to be coated and includes job-specific details. While the specification is a contractual guidance document, it is not typically **the** contract. Its purpose is to serve as the common point of technical reference for all involved in the project.

In general the specification will state:

- What to do.
- Where to do it.

It will not tell how to do it; the how is typically left up to the contractor so the work is done in the most efficient manner.

The specification lets the owner state what needs to be done on the project. Typically this includes the technical and organizational details that provide a basis to determine if the work was done as agreed. **A good rule of thumb** is that the more critical the coating is to the engineered performance of the structure, the more detailed the specification needs to be.

While it is important to include enough detail to ensure proper application, it is also necessary to avoid being overly detailed. Unnecessary detail can lead to excess cost and reduces contractor flexibility. Excess detail in the specification increases the chance of conflicting information, and conflict resolution can be very costly in the long run.

Few coating projects will not have some issues. So the specification needs to describe how any issues will be handled. Start by outlining then defining the roles and responsibilities of all parties, including but not limited to:

- One responsible party for each task
- Points of contact
- Specific responsibilities of each group involved in the process
- Reporting process
- Claims process
- Dispute resolution process

9.2 How to Create a Specification

An easy place to start a new specification is by reusing an older specification as a template. Ensure that you change the specification to reflect the current project. If you are going to reuse an older specification, before you begin, list the current coatings process from start to finish to ensure you incorporate all of the steps for the current project into the older specification template. Remember, each coatings project is unique and should be treated as such.

If you are starting from scratch, first break down the process and think it through one step at a time. Ask yourself some basic questions:

- What do I want to see accomplished?
- What is the reason for coating this?
- Is the coating aesthetic, protective, or critical to performance?
- What performance expectations do I have for the coating?

Outline your expectations and include specific details that are both technical and organizational. Technical details include measurements and readings such as surface profile, surface cleanliness, film thickness, etc. Organizational details include work practices and processes. These include hours available for work, clean-up processes, waste practices, etc.

The specification is made up of about 17 different elements. Each element generally outlines a particular step within the work process.

9.3 Elements of the Specification

These elements are commonly included in a specification.

- General (overview)
- Terms and definitions
- Reference standards and codes
- Scope of work
- Pre-job conference
- Coating schedule
- Site conditions
    - Safety
    - Environmental
    - Occupational safety and health

- Surface preparation
- Coating materials
- Workmanship
- Coating application
- Work schedule
- Repair procedures
- Paint warranty
- Quality assurance
  - Inspection
- Documentation and submittals
- Resolution of conflicts

9.3.1 General

The **general** section of the specification is often used as an introduction to the project. It may include a wide variety of. This is typically basic information about the owner, points of contact, and procedures for conflict resolution.

The General section often includes:

- Owner's name and address.
- Job number.
- Designated representatives of the parties.
- Details regarding the responsibilities of the parties to the contract.
- Other items of general interest.

The individuals named in the general section have the ability to interpret or modify the technical, schedule, or financial aspects of the contract.

9.3.2 Terms and Definitions

The terms and definitions section focuses on defining the intent of specific words. Confusion and misinterpretations can occur if the intent of a term is not clear. By defining the intent of specific terms, all of the parties are on the same page and know what is meant when a particular term is used.

This section is often presented as a list of terms and their associated definitions. The list should define common terms to avoid multiple interpretations of the term.

When including definitions:

- Use industry consensus terms/definitions when possible.
- Use definitions that clarify/avoid ambiguity.
- Use definitions that are measureable and/or enforceable.

For example:

> "Following waterjetting a steel surface, that "moderate" flash rusting will be the maximum acceptable amount of flash rusting."

Without further definition, "moderate" could be taken as a variety of different states. Confusion can be minimized by defining the term "moderate." By referencing NACE No. 5, *Surface Preparation and Cleaning of Metals by Waterjetting,* within the definition of moderate flash rust. Furthermore, "flash rusting" can have a variety of definitions. The words could refer to the rusting which occurs immediately after application of a waterborne paint as well as after waterjetting.

Definitions should also be specific to your needs. For example if your specification states:

> *"Remove all* **damaged** coating prior to paint application."

And you define *damaged* using the American Heritage Dictionary as:

> *"Harm or injury to property or a person, resulting in loss of value or the impairment of usefulness.*"

You can see that this definition would be too vague and ambiguous to help answer, "Is this coating damaged?" Instead, define the term damage through the use of **common industry terms** such as: rust-through, cracking, checking, blistering, etc., whatever you choose to define as "damaged."

Trade associations such as NACE and SSPC have published glossaries of industry specific terms that are considered the "industry consensus".

Consistency is important when you are using defined terms throughout the specification. Be consistent in usage throughout the specification and contract documents. Try not to use terms interchangeably to avoid confusion. For example, if a specification is referring to "flash rusting" on the substrate due to waterjetting and residual "surface corrosion" present from in-service use of the component, both terms refer to a visible corrosion product on the surface, but they are not interchangeable.

9.3.3 Reference Standards and Codes

The Reference Standards and Codes section clearly delineates the standards and codes used in the work specification. Listing the applicable standards and codes in one place alerts everyone to guidance documents that they will have to know and follow. Types of standards and codes to be referenced include:

- Work practice standards.
- Quality assurance test standards.
- Safety codes.
- Environmental codes or regulations.

Never reference standards or codes that are not part of the specification. This can confuse anyone responding to the solicitation.

Make sure that the specifications are properly referenced and include the edition. If there are changes to the reference document after publication and before work beings, the general rule of thumb is that the governing standard for the job is the standard that is in effect on the publication date of the invitation to bid.

In addition to properly referencing the standard, make sure you understand all that the reference entails. Ask yourself these questions:

- What does the reference require the specifier to determine?
- What superficial or contradictory information is in the reference standard?
- Are there any requirements in the standard which should be excluded?
- What obligations do the reference standards put on the specifier?

Reference standards usually are not complete and you may need to include additional information. For example if you are using NACE No. 2 to specify surface abrasive blasting, you must include the specific surface profile wanted.

There are often minor, and sometimes major, conflicts between product information, contract specifications, and reference specifications, e.g., a manufacturer's product data sheet may only require a NACE No. 3 surface while the specification requires NACE No.2.

A specification may reference NACE No. 2 with some exception (e.g., the allowable "staining" may include intact mill scale). The coating specification should detail how to deal with such conflicts. To avoid ambiguity, include an order of precedence for which standards govern in the event of a conflict.

Industry standards are available from such organizations such as NACE International, SSPC, ASTM, AWWA, ANSI, ACI, API, and ISO. These organizations provide complete listings of their standards on the Internet.

Common ASTM standards for the coatings industry include:

PREPARING SURFACES FOR COATING

D2092: Practice for Preparation of Zinc-Coated (Galvanized Steel) Surfaces for Painting

D4258: Practice for Surface Cleaning Concrete for Coating

D4259: Practice for Abrading Concrete

D4260: Practice for Acid Etching Concrete

D4261: Practice for Surface Cleaning Concrete Unit Masonry for Coating

D4262: Test Method for pH of Chemically Cleaned orEtched Concrete Surfaces

D4263: Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method

D4285: Test Method for Indicating Oil or Water in Compressed Air

D4417: Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel

D4940: Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives

E337: Test Method for Measuring Dry Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

PHYSICAL PROPERTIES – WET FILMS

D3925: Practice for Sampling Liquid Paints and Related Pigmented Coatings

D4212: Test Method for Viscosity by Dip-Type Viscosity Cups

PHYSICAL PROPERTIES – CURED FILMS

D2240: Test Method for Rubber Property – Durometer Hardness

D2583: Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor

D3359: Test Methods for Measuring Adhesion by Tape Test

D3363: Test Method for Film Hardness by Pencil Test

D4541: Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

D4752: Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub

THICKNESS MEASUREMENT

D1005: Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers

D1186: Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base

D1400: Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base

D4138: Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means

D4414: Practice for Measurement of Wet Film Thickness by Notch Gauges

HOLIDAY DETECTION

D4787: Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates

D5162: Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates

VISUAL EXAMINATION AND APPEARANCE

D4214: Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films

D4610: Guide for Determining the Presence of and Removing Microbial (Fungal or Algal) Growth on Paint and Related Coatings

GENERAL TOPICS

D16: Terminology Relating to Paint, Varnish, Lacquer, and Related Products

D3276: Guide for Painting Inspectors (Metal Substrates)

D4227: Practice for Qualification of Journeyman Painters for Application of Coatings to Concrete Surfaces of Safety-Related Areas in Nuclear Facilities

D4228: Practice for Qualification of JourneymanPainters for Application of Coatings to Steel Surfaces of Safety-Related Areas in Nuclear Facilities

D4537: Guide for Establishing Procedures to Qualify and Certify Inspection Personnel for Coating Work in Nuclear Facilities

D4538: Terminology Relating to Protective Coating and Lining Work for Power Generation Facilities

Common NACE and SSPC standards for the coatings industry include:

SSPC-VIS 1: Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning

SSPC-VIS-2: Standard Method for Evaluating the Degree of Rusting on Painted Steel Surfaces

SSPC-VIS 3: Guide and Reference Photographs for Steel Surfaces Prepared by Hand and Power Tool Cleaning

SSPC-VIS 4/NACE VIS 7: Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting

SSPC-VIS 5/NACE VIS 9: Guide and Reference Photographs for Steel Surfaces Prepared by Wet Abrasive Blast Cleaning

SSPC-SP 1: Solvent Cleaning

SSPC-SP 2: Hand Tool Cleaning

SSPC-SP 3: Power Tool Cleaning

NACE No. 1 / SSPC-SP 5: White Metal Blast Cleaning

NACE No. 2 / SSPC-SP 10: Near-White Blast Cleaning

NACE No. 3 /SSPC-SP 6: Commercial Blast Cleaning

NACE No. 4 / SSPC-SP 7: Brush-Off Blast Cleaning

NACE No. 5 / SSPC-SP 12: Surface Preparation and Cleaning of Metals by Waterjetting Prior to Recoating

NACE No. 6 / SSPC-SP 13: Surface Preparation of Concrete

NACE No. 8 / SSPC-SP 14: Industrial Blast Cleaning

SSPC-SP 15: Commercial Grade Power Tool Cleaning

NACE No. 10 / SSPC-PA 6: Fiberglass-Reinforced Plastic (FRP) Linings Applied to Bottoms of Carbon Steel Aboveground Storage Tanks

NACE No. 11 / SSPC-PA 8: Thin-Film Organic Linings Applied in New Carbon Steel Process Vessels

NACE No. 12 / AWS C2.23/SSPC-CS-23.00: Specification for Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

SSPC-SP 11: Power Tool Cleaning to Bare Metal

SSPC-PA 1: Shop, Field, and Maintenance Painting of Steel

SSPC-PA 2: Measurement of Dry Coating Thickness With Magnetic Gauges

SSPC-AB 1: Mineral and Slag Abrasives

NACE SP0302: Selection and Application of a Coating System to Interior Surfaces of New and Used Rail Tank Cars in Molten Sulfur Service

NACE Standard RP0402: Field-Applied Fusion-Bonded Epoxy (FBE) Pipe Coating Systems for Girth Weld Joints: Application, Performance, and Quality Control

NACE Standard RP0602: Field-Applied Coal Tar Enamel Pipe Coating Systems: Application, Performance, and Quality Control

NACE Standard TM0102: Measurement of Protective Coating Electrical Conductance on Underground Pipelines

9.3.4 Scope of Work

The **scope of work** section provides an overview of the work. Typically it lists the structures that are part of the work package and generally describes the work to be performed. Sub-sections include:

- Purpose of the work

- Project goals and objectives
- General information on the work

The scope of work section can also outline the remaining portions of the specification, drawing attention to key parts of the work package and particular work sequencing issues.

9.3.5 Pre-Job Conference

The **pre-job conference** is a key, but sometimes overlooked, part of the specification and contract development process. The pre-job conference is held after the contract has been awarded and before work progresses. The primary intent is to foster a constructive discussion about the project, especially the specification, and to allow all parties to ask the questions needed to progress properly and promptly on the job. Not all parties will agree on the outcome, but the intent is to reduce downstream conflict.

Key personnel who should attend the pre-job conference include:

- The owner or owner's representative.
- The project designer.
- Contractors.
- Those responsible for quality assurance/inspection.

During the pre-job conference it is important to define each person's role in the process. For example, the specification should state whether or not the quality assurance person (inspector) can halt the contractors' work based on findings. Another example would be defining exactly who is allowed to okay modifications/ change orders to the contract. The pre-job conference should include a site visit, if possible, so all parties are aware of the job location and its current status.

Some owners may hold a very similar meeting, referred to as a pre-bid conference, wherein a meeting is held before bidding the contract to discuss similar issues. While a pre-bid conference is a good idea, it does not eliminate the need for a pre-job conference. A pre-job conference will be a more frank discussion, is more timely to the actual project schedule, and is likely to have more appropriate people attend (i.e., the day-to-day managers vice estimators).

The specification will typically indicate:

- When and where a pre-job conference will be held.
- Mandatory attendees at the meeting (usually by title) — principally those who have been named as primary points of contact within each respective organization with the authority to interpret or modify the technical practices, scope of work, schedule, or cost of the contract.
- Any requirements which are to be met before the pre-job conference, i.e., specific submittals such as environmental plans, safety plans, occupational health plans, staffing plans, etc.
- Method of how interested parties will be informed of any changes to the specification resulting from the conference.

During the pre-job conference designate a single person to take detailed notes and document the proceedings. These notes should be track the conversation and may include interpretations of specific words, standards, or the specification in general. After the conference, formalize the notes and formally distribute the conclusions (and final rulings) to all involved parties. The notes should delineate any modifications or clarifications discussed during the meeting. Ensure the modifications/clarifications do not affect the contract. If they affect the contract, address the contract concerns prior to the start of the project.

9.3.6 Coating Schedule

The **coating schedule** provides a detailed list of all structures and portions of the structure to be and not to be coated under the specification. It also identifies different coatings and surface preparations by item.

This information is typically presented in a table to aid the contractor in visualizing exactly what they are going to be working on. If further explanation is needed, include notes about the items to be coated in the list. This list is helpful in that it provides a simple reference for all the work to be completed.

While the schedule is often in the form of a table, this may not always convey the owner's need. A specific example would be applying multiple coating systems to a complex component. In this example, the coating schedule may be best presented in the form of a detailed drawing, or series of drawings. This format may be more conducive in applications where different coatings are used on alternative surfaces of the same part — perhaps to facilitate component assembly or to impart a specific engineering property to a small area of the structure.

In listing all of the components to be coated within the specification, the owner specified all of the surfaces to be coated – surfaces that are typical (steel) and surfaces that are less common (concrete, aluminum, stainless steel). This is important in that different surfaces will need to be dealt with in different ways and the contractor should be able to plan accordingly.

9.3.7 Site Conditions

The site conditions section addresses the conditions at the site which can affect work, including:

- Utility availability.
- Safety.
- Environmental.
- Occupational health.
- Hazardous materials and operations.

Failure to acknowledge any of these can be detrimental to the project process and can cause significant fines, costs, and delays.

9.3.7.1 Utility Availability

Utility availability needs to be addressed prior to the start of the project. If you are blasting or painting, requiring the use of a compressor or humidity control, you will need electricity. If electricity is not available, you will need to plan ahead and obtain a portable generator. The portable generator and all of the equipment will have to fit within the location constraints.

This section of the specification should outline the available utilities including:

- Electricity
- Water
- Sewage
- Office (phone, fax, internet)
- Restrooms

9.3.7.2 ESOH (Environmental, Safety and Occupational Health)

ESOH covers a wide range of issues. In general, environmental issues can be defined as control of emissions (air, water, and land) and hazardous material (HAZMAT) disposal. Safety refers primarily to the job site — maintaining a safe workplace to avoid worker accidents. Occupational

health typically refers to practices to ensure that workers are not suffering from chronic or acute health risks in response to conducting the work.

ESOH issues should reflect the requirements of each specific job.

The specification language should be tailored to the job at hand.

ESOH plans for different owners performing the same task can vary widely. Primarily, this reflects on the owner's experience with ESOH issues on previous tasks and the degree of conservatism on the part of the owners. It can also be influenced by other ESOH compliance programs that the owner may be operating under. A particular owner may have a VOC emission limit; contractors working with an owner's facility may have to minimize emissions for the owner to remain in compliance with their local regulations.

There are several options for ESOH plans and the level of detail contained within:

- **Option 1**: Specify nothing – the contractor must follow the law
    - Benefit: No burden on the owner to identify laws
    - Drawback: Completely rely on the contractor to understand the regulations for owner's facility
- **Option 2:** Provide general guidance, especially on key ESOH elements
    - Benefit: Contractor is at least aware of any major regulations
    - Drawback: Contractor may tend to follow only the rules laid out
- **Option 3**: Detail exactly what must be done
    - Benefit: All regulations are clearly stated, no room for interpretation
    - Drawback: Costs may increase drastically

9.3.7.3 Environmental

There are numerous environmental concerns associated with the coatings process. The extent of the concern differs depending on the location of the work to be done, so the specification writer must understand the federal, state, and local legislations to which the contractor will be held. There may also be plant or company-specific environmental regulations - for instance a plant that was built on the condition that they respect the local bald eagle population has "special" rules about working around nesting areas.

The environmental section of the specification commonly lists the key environmental regulations that:

- Are likely to increase the cost of the work.
- Are likely to draw the most regulatory attention as they post the highest risk of non-compliance.

Another key environmental area for coatings projects is HAZMAT handling. Typically, the owner has the responsibility for HAZMAT handling and disposal— they are the generator of the waste, not the contractor. Most owners are specific about what they expect or require from the contractor with regards to HAZMAT within the specification and contract documents.

You may want to include the following in your specification:

- Environmental management plans - discuss an overview of responsibilities and programs the contractor will undertake to ensure environmental conformance.
- Work area limits - discuss control of runoff from the job site. Water control is important. Issues include eliminating material spills into water streams. There are also variations in local rules concerning the discharge of process water into the local environment. They are not uniform from locality to locality.

- Air emissions - typically include paint dust and chemicals, but can also include less considered issue, such as “noise” pollution. In some work which is located close to habituated (living) areas, work hours will be constrained as a result of “noise” pollution — impacting the contractor’s overall project cost.

9.3.7.4 Safety

It is often a good idea to consult with a site safety coordinator when preparing the specification. They will be your greatest source of information and should be able to outline the required and desired safety practices. Incorporate these job specific practices into the specification, especially issues that may be difficult for a contractor to recognize without previous on-site experience. This can include peripheral issues like traffic control and the need for a flagger on site. If the contractor comes to the site unprepared, it could cause the entire schedule to slip.

The specification should make reference to availability of the Material Safety Data Sheets (MSDSs) and how they are to be maintained – typically a copy will stay with the contractor. Prior to any material usage however, both the owners and contractors should also review the applicable MSDS sheets for the products used on the job site.

An owner’s insurance company may demand that any outside contractors have a maximum experience modification rate (EMR), which reflects their safety practices. This information is usually used when selecting a contractor, however, the specification may state that the contractor must maintain a specific EMR for the entire length of the job.

A contractor should have a safety program designed by a Certified Safety Professional or Industrial Hygienist prior to engaging in any coating project. Before beginning work, a job safety analysis may be conducted to identify local hazards.

The specification should:

- Communicate Requirements - Codes and Standards (Federal, State, Local, Site).
- Communicate Expectations - Specific Safety Tasks.
- Identify inspection points.

9.3.7.5 Occupational Health

The owner should ensure that the contractor has an effective and complete industrial hygiene program. While often considered a contractor's responsibility, unsafe practices can still result in lawsuits targeting the owner which can then impact the overall project cost and schedule.

Workers should be adequately trained for the work they are performing. Using equipment in an unsafe manner to accelerate the work is not acceptable.

From a project design standpoint, worker protection is not synonymous with Personnel Protective Equipment (PPE). Engineering design is the preferred mode of ensuring workers’ health protection. The specification should state:

- Occupational health is the contractor’s responsibility.
- The contractor should have an occupational health plan that contains specifics on:
    - Worker training
    - Application of engineering controls first, then PPE as a back-up.
    - Medical surveillance program.
    - Air sampling/breathing space monitoring.
    - Heat stress.
    - Confined space.
    - Lock-out-tag-out.

9.3.7.6 Hazardous Materials or Operations

Hazardous materials and operations must include what the contractor will touch as well as any surrounding areas the contractor needs to be aware of. For example, a pipeline running at a very high temperature five feet away from where the contractor will be painting is a hazardous operation that should be pointed out within the specification. Not only is this situation hazardous to the contractor personnel in that they may accidentally burn themselves, but there is a good chance that at least one part of the coatings process will be flammable, so it would be best to not be stored near the high temperature pipeline.

9.3.8 Surface Preparation

The next element of the specification is surface preparation. Surface preparation is essential to any type of coating project. Prior to the mechanical preparation of the surface, the surface must be:

- Cleaned and/or degreased
- Dismantled appropriately (if necessary)
- Accessed
- Taped and/or masked
- Contained

Each of these items should be addressed within the specification, either in detail or through reference to applicable industry specifications.

The specification should also state the:

- Type of surface preparation – including referenced standard.
- Materials to be used and associated requirements – such as grit type and recyclability.
- Surface profile requirement.
- Surface contamination requirements.
- How to handle issues specific to the substrate — welds, bug-holes, recessed areas, sharp edges.
- Hold points for inspection criteria.

You should also consider the mechanical means of surface preparation and how they may vary from area to area of the substrate. This variation can depend on the size or configuration of the structure; it may not be physically possible to get the same type of tools to the entire structure. A structure can be made of different materials or the same material of different strengths. Thus surface preparation would require the use of more than one preparation standard.

The location of the structure can influence the preparation method. For example, with lead paint abatement there is a tendency to reduce the use of dust-generating methods of surface preparation in areas that may come in close proximity to the general public.

A designer may also have found it cost-beneficial to apply different methods of surface preparation to different areas of the same structure, thus saving the most stringent preparation for the most corrosive areas. Thus a specification will have to clearly delineate start and stop areas for each method.

The specification should also state the estimated work area size for each type of surface preparation. Provide detailed dimensioned drawings or an owner's estimate of these areas, or allow the contractor access to the structure pre-bid to make their own estimates. Knowing the work area size allows the contractor to determine the tools and materials they will need and the amount of labor it will take.

9.3.9 Coating Materials

The coating materials section of the specification defines the specific coating materials and all details impacting their application. This section compliments the “Coating Schedule” part of the specification. It includes details on:

- Material requirements.
- Material delivery and handling.
- Material storage.
- Material collection and disposal.
- Mixing practices.
- Thinning practices.
- Curing.
- Touch-up coats.
- Stripe coats.

Usually you can obtain this information from owner testing or from manufacturer’s technical data sheets after product selection. In some instances the requirements may be based on other data, procedures or testing.

There are many ways to specify the coating materials for a project. Detail in this area normally depends on the owner’s resources and experience with the materials. There are several ways to stipulate your coating selection. Commonly used terms:

- Sole-source identification
  - Specification will state that only product “X” purchased from corporation “Y” will be acceptable
- Qualified Products List (QPL)
  - Specification references a specific qualified products list. The list is a predetermined group of coatings that meet certain characteristics and performance testing requirements. All of the coatings on the QPL are acceptable for the job. Either single coatings or coating systems (multiple coating components) may be included on the QPL.
- Generic Description:
  - Specification states that a type or class of product will be acceptable, such as “red polyamide epoxy primer”, without including performance details.
- Performance Requirements
  - Specification states that any coating that meets specific performance requirements is acceptable. An example would be “10 year service life with a resistance to acetic acid”. Any coating for which documented proof of meeting the performance requirement would be deemed acceptable.

There are a few benefits and drawbacks to each of the product selection types. A sole-source arrangement may not be permitted by all owners and may increase material costs, but it also ensures you get the product you want. A generic description might be low cost, but there are countless products that could meet most “generic” descriptions. Qualified product listings are effective, but are costly for an owner to maintain and update. Performance requirements sound optimal, but someone must be responsible for certifying the performance of the coating with these requirements. Avoid using wording such as “or equal” since that term is difficult to confirm.

When defining the owner's choice of products, add the requirements for specific product numbers (if known), the color and gloss of the products, and the thinners to be used (if any) to apply the product. An owner will list alternative coatings that may be used that are compatible to changes in the local weather conditions, example higher/lower temperature days. Adding this flexibility may allow the contractor to continue work and complete a job on schedule, assuming that the alternative products still meet the owner's performance goals.

Often the specification requires sampling of coatings. Samples of the coatings may be required for various reasons including color comparison and lot acceptance. They could also be retained for evaluation if something goes wrong at a later date. While most manufacturer's processes are well controlled, there can be a problematic batch of paint. A retain of the paint (which is a small, wet sample of the paint) used on the project is usually the only way to prove such problems. The specification should describe exactly how the samples should be taken, how they are to be evaluated, and what decisions will be made with the results (if any). This information should include the type of samples to be taken:

- Liquid – to measure coating fingerprint, identify pigment, etc.
- Dry Film – to measure color, gloss, etc.

In addition it should include the sampling methodology, how many samples are required, who will take the samples, where they will be kept, and for how long.

Other questions to consider are:

- Will you allow your contractor to thin the paint?
- Are their limits that an owner might be concerned about due to the impact of thinning on product performance or environmental regulations?
- How is the owner going to confirm cure?
- What are the requirements, if any, for touch up and stripe coating?

The majority of information on the coating material is found on the manufacturer's product data sheet:

- Product description
- Recommended uses
- Specification data
- Color
- Finish
- Reflectance
- Clean-up methods
- VOC content
- Percentage of solids
- Film thickness requirements
- Coverage
- Drying/cure times
- Pot life
- Thinning

- Surface preparation requirements
- Application procedures

Carefully review all of this information to ensure it is properly conveyed in the specification. Conflicts between the manufacturer's data and the owner's experience or specification should be resolved before starting work. You should also review the MSDS to ensure critical safety information is properly listed in the Safety section of the specification. The specification should state that the contractor is required to maintain (at least a copy) both the product data sheets and the MSDS.

9.3.10 Coating Application

The owner usually specifies how to apply the coating to the structure. The specification may address:

- Application tools. Designs of spray guns or equipment to meet environmental restrictions or productivity requirements. An owner may require the use of hand tools for application of the coating so that overspray does not damage surrounding equipment.
- Wet /dry film thickness for each individual coat and for the total system. This includes tolerance ranges for each coat and the minimum/maximum acceptable thickness of the complete system. An ideal specification will also stipulate the contractor action if this minimum/maximum is not met.
- Stripe Coat. The specification will also detail the stripe coating procedures needed, if any.
- Coating specifics.
    - Same or contrasting color material
    - Overcoating procedures - applied to fully cured or "wet-on-wet"
    - Full coats, tack coats, stripe coats
- Environmental condition requirements.
- Required process checks (inspection points).
- Acceptance criteria for
    - DFT
    - Adhesion
    - Appearance
    - Coverage (holidays/pinholes)
    - Degree of cure

Improper coating application is the number one reason why coatings fail prematurely.

9.3.11 Workmanship

A specification will typically list workmanship and work habit requirements. Issues concerning workmanship should be clearly stated in measurable terms as they define the expected competence. "Good workmanship" is difficult to define. Define good workmanship in terms of what you want out of the job – for instance, no runs, sags, drips, etc.

Work habits address site appearance. Some projects may be ongoing in full display of the public. It is in the owner's interest to present a competent crew to the public. Thus requirements should be specified for site cleanliness or the construction of cosmetic containment that obscures the industrial work from the public view.

9.3.12 Work Schedule

Include time constraints/requirements for the work in the project specification. List the target dates for completion as well as the preferred work sequencing. For example, if you are applying a floor coating that must cure in time for the store to open the following day or coating a ship that will set sail in ten days, you need to state that in the specification.

The schedule should also list work times when access will not be allowed to the project. On jobs where the coating work is integrated into other project work on the structures, the owner may stipulate a work sequence as part of the schedule that will allow the owner to cut the work off at a particular point should the contractor fall behind schedule. This may be necessary to protect the owner and ensure continued functionality of the structure, even with a less than ideal coating.

Also list any limitations on the available access of the structure within the specification. Each day/shift work schedule must incorporate a certain amount of start-up and clean-up time.

Finally, list any expected coordination issues with other contractors working at the same site. Such interferences can often lead to problems for both contractors if their respective work schedules are not coordinated. Discuss the work schedule in detail at the pre-job conference, to ensure that all parties involved know the time constraints.

9.3.13 Repairs and Remedial Work

Outline how to handle repairs and remedial work in this section of the specification. It should include how and when to perform repairs. Include repairs for small defects created in the coating during removal of scaffolding, for example. Several such cosmetic defects might be created in the coating over the construction period and it may be best to repair these at the end of the project.

In addition to how and when to perform repairs, include information on when the repair work is presented for acceptance and who is responsible for determining any unanticipated repair procedures. Having these issues clearly delineated will ease the repair and rework process and make sure that any mistakes are taken care of quickly and efficiently. This is truly an important step, because any defects in the coating will affect the overall service life of the coating.

Poorly repaired locations may fail well before the remainder of the coating and drive up future maintenance costs, so take the time to specify and perform proper repairs. The specification should anticipate repair scenarios. For example, it is common to specify different repair procedures for some defined small area (e.g., less than 3 square inches) versus larger areas. Also, it is common to require a full topcoat after spot repairs in locations where appearance is important. But for a structure of 1,000 ft^2, 0.3% of the area is only 3 ft^2 or about 100 little “dings” in the paint of 3 in^2. Most coatings are considered “failed” when more than 95% of the coating remains intact, so you must carefully stipulate the repair requirements.

9.3.14 Paint Warranty

If the owner required a paint warranty, the specification should clearly detail its requirements. Most specifically:

- How does one determine failure?
- When is the coating to be inspected and by what technique?
- Who is performing the inspection, the owner or the contractor?
- What is the recourse if any failure is noted?
- Does the contractor have to possibly recoat the entire structure? Is partial repair acceptable?
- Does the repair requirement depend on the location and extent of failure?
- Is there a financial penalty, i.e., withholding of a final payment?

- How does the owner ensure they can collect on a warranty 'x' years after the job is complete? Is there a performance bond?

9.3.15 Quality Assurance

The quality assurance section of the specification includes information on both quality assurance (QA) and quality control (QC). While related, there are significant differences between the two:

- QA – Typically involves test and inspection to ensure work being performed complied with the specification. This is typically done by an inspector.
- QC – Typically involves a plan written by the contractor as to how they are going to ensure that the customer receives a quality product.

The specification should detail the requirements for both QA and QC. Does the owner want to see a contractor's QC plan and any associated records, e.g., records for proper mixing of the paint, wet film thickness, etc.

The quality assurance section within the specification may also include:

- Requesting qualifications and/or certifications of the contractor and the contractor's personnel. This can include company-wide certifications (SSPC-QP-1, SSPC-QP-2, SSPC-QP-3 for qualifying painting contractors) and certifications of key personnel (blaster/painter requirements, inspector requirements).
- Field sampling plan (inspection plan). This information should include the number and frequency of tests and what will be tested.

Note that the field sampling plan can either be created by the owner or by the inspector, depending on the situation and the owner's knowledge of inspection procedures. The specification will state either plan.

9.3.16 Inspection

An inspection can include many potential elements and / or hold points. Hold points are those items which need to receive the owner's or owner representative's approval before the contractor can proceed. Some of the most common inspection points that will appear in a painting specification:

- Total system dry film thickness
- Ambient conditions during surface preparation
- General surface condition before cleaning
- General surface condition after cleaning
- Surface preparation equipment operation and abrasive size/type
- Abrasive cleanliness
- Compressed air cleanliness
- Soluble salt containment
- Ambient conditions during paint application
- Mixing and materials
- Application equipment operation
- Wet film/dry film thickness

- Stripe coat
- Visual appearance (runs, drips, sags)
- Repairs

Complex or special jobs may require additional inspection points. The information within the inspection plan should include the acceptance criteria for the aforementioned items. Inspectors will only inspect using the information provided within the specification and the inspection plan. So, if you do not want any sags within the coating on the structure, the specification needs to state that sags will not be acceptable.

The specification should also include details on the inspector's responsibilities, duties and areas of concern:

- Inspector's role
- Inspector's authority – Does the inspector have the ability to stop work?
- To whom the inspector reports and from whom the inspector takes direction
- Key deliverables from the inspector, including what records must be maintained

Many owners will hire 3rd party quality assurance personnel to perform real-time inspections of the contractor's work. While this is generally a good idea, it may not always be necessary. Prior to hiring an inspector, the owner should weigh if a member of the contractors staff or your own staff could perform the inspection duties. Depending on the sophistication of the job and the parties involved, this may be the best option and result in a decrease in costs.

If you do opt for a third-party inspector, there are different classes of inspectors available. The NACE Coating Inspector Program (CIP) has three levels of inspectors.

- Level 3: Has demonstrated experience in practical environments to a panel of peers when faced with coating-related scenarios. Is qualified to supervise NACE Coating Inspector Level 1 and 2 persons.
- Level 2: Has sufficient knowledge of specialized coating materials and techniques for the surface preparation and application used on a wide variety of substrates. Also has ample knowledge in advanced report writing, condition surveys, failure analysis, and refurbishment.
- Level 1: Is qualified to undertake basic coating inspection of structural steel using nondestructive techniques and instrumentation under the supervision of a NACE Certified Coating Inspector – Level 3. The person certified at this level has basic knowledge of coating materials and techniques for surface preparation and application on steel substrates.

The level of certification required depends on the needs stated in the specification. You can also hire non-certified inspectors who work under the direction of a certified inspector. Remember, there can also be inspections for activities other than painting, such as safety, work practice, HAZMAT handling, etc.

9.3.17 Documentation and Submittals

To ensure that the desired documentation is completed, outline expectations in the specification. Common types of documentation include:

- Progress records with a listing of where the project stands vs. schedule.
- Daily work sheets showing the actual accomplishments each day.
- Activities report which refer to specific tasks completed on the project.
- Material usage reports showing materials consumed on the job.

- Product Data Sheets/Material Safety Data Sheets.
- Work safety plans.
- Contractor points of contact.
- Certifications (for the company and workers).
- Containment and/or scaffolding design.
- Quality control plans.
- Product batch certifications.
- Inspection plans.

Keeping detailed records allows you to find causes related to failures, track progress vs. expectation, identify schedule/budget issues, or identify excessive material consumption.

The specification should define:

- The list of required documentation.
- When documentation should be submitted.
- The desired formatting – electronic, paper, tangible test materials.

9.3.18 Resolution of Conflicts

In the resolution of conflicts section of the specification, outline a procedure for the resolution of conflicts. Conflicts arise on every project, so defining a plan for resolving common problems will help assure project efficiency.

Specification should include specific conflict resolution guidance for conflicts within or associated with:

- The specification.
- A reference.
- The product manufacturer's instruction.
- Personnel conflicts between the owner, inspector and contractor.

This information should state who gets the final word about which path to follow.

9.4 Implementing the Specification

After you compile all of the information for each element of the specification into the formal final specification, read through the specification carefully. Check for details that may be conflicting. Look for any loop-holes or easy-outs you may have inadvertently included.

Make sure that you can defend the statements made within the specification and that they are not vague or ambiguous. Ask someone else to read through the specification and address any comments or confusion they have before finalizing the specification.

The specification can be properly implemented through three steps:

1. Disseminate the information in a timely manner. Make sure that all interested parties have the most up-to-date copy of the specification.
2. Hold all parties accountable for what was agreed upon within the specification.
3. Respond to any departures from the specification immediately as they arise.

By following these steps, the specification will guide the coatings process and provide answers as questions arise.

9.5 Departures from the Specification

A departure from specification (DFS) occurs when work is not performed to the conditions outlined in the specification. Departures from the specification are routine with any coatings project, but they can severely impact the coating system and should not be taken lightly.

DFS can lead to a myriad of problems for the coated structure. General problems associated with DFS include premature coating failure and additional rework needs. Additional rework can lead to falling behind on the project schedule and incurring additional project costs. Specific problems depend on the nature of the DFS. Several of these problems are discussed in detail in the *Effect of Specification Elements on Service Life of the Coating* section.

When a DFS occurs:

- Document the entire extent of the area affected. Maintaining documentation related to DFS can be useful in eventual failure analysis.
- Determine the appropriate repair/rework.
    - There may be a number of alternatives available. Weigh cost and effectiveness to determine which is the best solution.
    - Work as a team to determine the solution (owner, contractor, inspector, engineer, manufacturer, etc.)
- Implement the most appropriate repair/rework.
- Prevent political issues relating to blame, cost, etc. from sidetracking progress.

Following these steps will get the work back on track, and refocused on completing the original task at hand.

9.6 Specification Shortcomings

Sometimes, simple steps within the coating process get overlooked or left out of the specification. These seemingly insignificant areas can have a large impact on the service life of the coating. Areas that are commonly overlooked:

Welding: The amount of weld splatter left after surface preparation can cause coating holidays. Even the smallest of holidays can lead to full coating failure as well as surface and pitting corrosion. To avoid this issue specify the acceptable amount of weld splatter after surface preparation and have the inspector check for compliance with the specification.

Testing: In industrial painting, the structures being coated are typically very large, so it is impossible to test every square inch. Specify the number of measurements an inspector can reasonably take within a specified area in the limited time available. Even when inspecting in accordance with the specification, only a very small percentage of the total surface area can be inspected.

"Representative" samples of the entire surface can identify the worst areas, but it is up the inspector's discretion as to where it is easiest to take them (within arms reach for instance). The problem with sampling to identify the worst conditions is the visual assessment (a quick glance) that tells the inspector where to check. While both of these methods are commonly used practices you need to delineate which method the inspector should use.

Application: Specifications generally avoid stating "means and methods" of work practices. This allows contractors to perform work efficiently. Common application problems include:

- **Controlling Mix Ratio in Plural Component**. Having an incorrect ratio of component A to B will result in poor performance.
- **Using In-Line Heaters**. Material can overheat or not properly heat if the set up is incorrect. This can cause the coating to start curing prematurely or not at all.
- **"Hot-Potting."** Hot-Potting is mixing plural component paint in one container without the use of proper plural component machinery for application. This can cause the coating to begin to cure prior to application and you may end up with a bucket of cured paint.
- **Compressed Air Contamination.** Moisture or dirt can become entrapped within the coating. Excess moisture can affect the curing reaction and cause adhesion problems.
- **Paint Mixing**. Improper ratio of components, improper thinning either in quantity or with thinner type and not thoroughly mixing the components can occur with paint mixing.
- **Shelf Life**. Expired materials may not perform at the desired level. A common problem is that the chemical reaction that causes adhesion or cure may no longer fully function.
- **Pot Life.** Using material that has extended its pot life can result in coating failure. Paints with a designated pot life typically "set up" and become unusable shortly after the end of the pot life.
- **Induction Time**. Induction time typically allows for the chemicals within the paint to activate properly. Not waiting the proper amount of time before using the paint will affect the coating's performance.

9.7 Effect of Specification Elements on Coating Service Life

Compiling a detailed specification may seem like a daunting task, and you may ask yourself if the potential effects on the coating are truly worth the effort.

The following list describes common problems that have a direct impact on coating life by section of the specification:

9.7.1 Surface Preparation

Table 9.1: Surface Cleanliness: *Invisible Contaminants, Salts on Substrate*

Problems	Service Life Effects
• Aids in creating initial osmotic pressure that can blister a coating and/or create stress in a coating which aides in defect formation	• Data suggests that the probability of failure can increase by a factor of 2-7 for immersion service when the surface chloride level increases from 0 to 5 ìg/cm^2
• Salt under the substrate facilitates (catalyzes) charge transfer underneath the coating	• In a marine environment, salts under the coating film will accelerate the deterioration of the coating via undercutting by a factor of approximately 4. Eliminating the salt will extend the coating life significantly

Problems	Service Life Effects
• Salt under the coating obviates the need for ionic species to migrate throughout the coating to participate in the coating process	

Table 9.2: Visible Contaminants: Dirt, rust, etc.

Problems	Service Life Effects
• May hinder adhesion resulting in deterioration of the coating	• May significantly shorten service life if they are sufficient to comprise coating adhesion
• Visible contaminants may contain salts creating initial osmotic pressure across the film	• Should coatings over such contaminants survive immediate catastrophic failure, data suggests visible contaminants will have relatively low impact on service life.

Table 9.3: Surface Profile: Below the specified limit

Problems	Service Life Effects
• Reduces adhesion of the film to the substrate, allowing disbondment	• Profiles below specification may reduce service life of the coating by as much as 30%, depending on coating type and service
• Insufficiently constrains the film, allowing it to absorb more electrolyte, increasing the propensity for the formation of initial "conductive pathways" through the coating	

Table 9.4: Surface Profile: *Above* the specified limit

Problems	Service Life Effects
• A high surface profile may not be sufficiently covered by the coating	• High profile depth poses a minimal service life risk provided that holidays are not present
• Exposed peaks or thing coating over peaks are a potential site for coating breakdown	• Holiday detection and proper film thickness measurements can ensure the risk has been mitigated with an adequate coating

Table 9.5: Surface Profile: *Shape*

Problems	Service Life Effects
• Research indicates that the profile shape can be as critical to coating adhesion as depth of profile.	• An angular profile increases the service life of the coating by as much as 30% over long exposure periods versus rounded profiles
• Too smooth of a profile may reduce the film adhesion and not adequately constrain the coating	

Table 9.6: Flash Rusting

Problems	Service Life Effects
• May hinder adhesion resulting in deterioration of the coating	• The service life impact of flash rusting depends on the degree of flash rust and the service environment and has everything from no impact to significant impact
• Visible Contaminants may contain salts creating initial osmotic pressure across the film	

Table 9.7: Extent of Surface Preparation

Problems	Service Life Effects
• May hinder adhesion resulting in deterioration of the coating	• Appears to have a significant impact of coating service life, particularly when preparing weathered surfaces
• Visible contaminants may contain salts creating initial osmotic pressure across the film	• Coatings over SP-2 (with salt) vs. SP-10 may fail 10 times faster

Table 9.8: Weld Conditions and Edge Radiusing

Problems	Service Life Effects
• A smooth surface without sharp edges or other discontinuities decreases probability of film defects (thin film or exposed substrate) at or near edges and welds	• Surface irregularities increase the likelihood of holidays or low DFT areas, having the potential to impact service life significantly

Problems	Service Life Effects
	• The risk can be mitigated by using a holiday test to ensure adequate film coverage of the substrate

Environmental Controls

Table 9.9: Environmental Conditions: *Prepped Surface*

Problems	Service Life Effects
• Improper environmental conditions between surface preparation and coating application can lead to surface rusting or moisture	• Both situations pose a high risk for delamination of the coating unless the coating is specifically formulated for that purpose
• Surface rusting is analogous to flash rusting in that it may hinder adhesion and contain invisible contaminants	
• A wet surface while applying a may impact coating adhesion	

Coating Application.

Table 9.10: Coating Application: *Number of Coats*

Problems	Service Life Effects
• Multiple coats can be used to decrease the probability of film defects (i.e., holidays and discontinuities), especially when stripe coats are used on edges and welds	• The number of coats used to achieve a particular build does not seem to impact service life for properly cured, high solids coatings
	• Multiple coats can serve to ensure good workmanship

Table 9.11: Coating Holidays

Problems	Service Life Effects
• Coating holidays or misses allow immediate access of water and ionic species to the substrate. This creates a local anode relative to the coated areas	• Holidays may moderately to significantly shorten the service life of the coating due to substrate corrosion, staining, disbondment/undercutting of the film

Problems	Service Life Effects
	• The use of CP may limit the significance of holidays on the coating life

Table 9.12: Paint Curing: *Coating Cure*

Problems	Service Life Effects
• The use of CP may limit the significance of holidays on the coating life	• Improperly cured coating will have a severely compromised life and should not be allowed
• Holidays may moderately to significantly shorten the service life of the coating due to substrate corrosion, staining, disbondment /undercutting of the film	

Table 9.13: Paint Thickness: *Film thickness;* <u>too thin</u>

Problems	Service Life Effects
• Lower film thickness increases the propensity for the formation of initial "conductive pathways" through the coating	• Research suggests that each coating has some critical minimum thickness below which service life may be significantly impacted
• Lower film thickness increases the probability of coating holidays	• In extreme cases, service life may be shortened by more than half

Table 9.14: Paint Thickness: *Film thickness;* <u>too thick</u>

Problems	Service Life Effects
• High film thicknesses can create internal stresses in the coating which tend to crack over time	• Brittle coatings can have a high risk of failure
• Thicker films may be too brittle to adsorb mechanical forces in service.	• Uncured materials may take up water more easily and in extreme cases may result in a material which is skinned over which has a high risk of failure
• Thick films may entrap solvent such that they do not fully cure	

Adhesion

Problems	Service Life Effects
• Coating adhesion is important to act against the forces of de-adhesion that occur around active corrosion sites in the coating. This can reduce the extent of corrosion	• Poor coating adhesion will adversely impact service life if it is sufficiently low. Unfortunately a “sufficiently low” adhesion value has not been easy to quantify
• Coating “pseudo-adhesion,” or the appearance of adhesion in coatings with a high cohesive strength, can act to limit the magnitude of physical disbondment of a coating; in turn this limits the physical magnitude of the pathway under the coating and the rate of local corrosion	• Coating adhesion is impacted by the adsorbtion/desorbtion of electrolyte

Table 9.15: Overcoat Windows: *Recoat interval; too short*

Problems	Service Life Effects
• Paint will not adequately dry before next coat is applied leading to poor adhesion	• Poor adhesion can lead to reduced coating performance and potential premature failure
• May entrap solvent such that the primer does not fully cure. Entrapped solvent and moisture can lead to blistering which can create holidays in the coating	• Blistering and holidays may moderately to significantly shorten the service life of the coating

Table 9.16: Overcoat Windows: *Recoat interval; too long*

Problems	Service Life Effects
• Paint may not correctly bond to the previous coat	• Typically missing a recoat interval will not greatly affect the service life of a coating although there is a potential for poor adhesion between coats
	• Missing a recoat interval creates more work and may affect the overall project schedule
	• After missing a recoat interval, in general the surface will be abraded and/or a tie coat applied prior to the application of the next coat

Table 9.17: Stripe Coats

Problems	Service Life Effects
• Poor edge retention can lead to coating holidays	• Holidays may moderately to significantly shorten the service life of the coating due to substrate corrosion, staining, disbondment/undercutting of the film
• Poor stripe coating can lead to the coating pulling back from the edges	

The best way to mitigate the effects described in this section is to maintain detailed requirements within the specification for each.

PCS 2 Advanced
List of Figures

Chapter 10: Surveys and Maintenance

PCS 2 ADVANCED
LIST OF TABLES

Chapter 10: Surveys and Maintenance

PCS 2 ADVANCED
TABLE OF CONTENTS

Chapter 1: Coating and Lining Issues in Various Industries

Chapter 2: Coatings Overview

Chapter 3: Convertible Coatings

Chapter 4: Non-Convertible Coatings

Chapter 5: Specialty Coatings

Chapter 6: Testing Coating Properties and Performance

Chapter 7: Surface Preparation Methods for Various Substrates

Chapter 8: Coatings Selection

Chapter 9: The Coatings Specification

Chapter 10: Surveys and Maintenance